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The Editor's Corner

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It is with deep sorrow that we report the passing of Michael (“Mike”) Freilich, Former Director of NASA’s Earth Science Division (ESD) from 2006 to 2019, on August 5, 2020. Mike was instrumental in moving forward the mission of the ESD during his tenure, with contributions ranging from programmatic advances to fostering the growth and development of many researchers and engineers and their respective scientific research and technology activities. His activities covered all the best parts of leadership, partnership, and mentorship. Mike’s energies covered a broad range of activities beyond the professional, to the benefit of all with whom he came into contact.¹

Mike had great passion for NASA Earth Science, which was evident whenever he spoke about it. Whether he was in front of NASA’s Hyperwall at a conference (see photo below and on page 20), speaking before a Senate sub-committee, meeting with international partners to discuss a new mission, or at the many other venues he found himself interacting with others as Director of ESD, Mike’s energy and enthusiasm for what he did was always evident—and often made a lasting impression on his colleagues. His enthusiasm and passion for our planet was evident in the remarks he made for the fiftieth anniversary of Earth Day just a few months before his passing (<https://www.youtube.com/watch?v=QdSCKLrC4Fg>).

The ongoing successes of NASA’s Earth Science program, which *The Earth Observer* has been chronicling for over three decades, are part of Mike’s legacy. Our team here at the Science Support Office specifically wishes to recognize Mike’s encouragement for the communication activities of the office—including *The Earth Observer*. His passing is a tremendous professional and personal loss to many—and he will be missed.

¹ To learn more about Mike Freilich’s life and legacy, see “Symposium on Earth Science and Applications from Space with Special Guest Michael Freilich,” in the March–April 2020 issue of *The Earth Observer* [Volume 32, Issue 2, pp.4–18—<https://go.nasa.gov/3lsbsDG>].

continued on page 2



Michael (“Mike”) Freilich, Former Director of NASA’s Earth Science Division (ESD) from 2006 to 2019, passed away on August 5, 2020. Mike loved NASA Earth Science, which was evident whenever and wherever he spoke about it. He loved to tell the stories of NASA Earth Science and was extremely supportive of the division’s communication activities. This photo of Mike was taken during NASA’s Earth Day 2018 celebration at Union Station in Washington, DC, while he was waiting to give opening remarks in front of the Hyperwall. **Photo credit:** NASA

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Reminder: To view newsletter images in color, visit eosps.nasa.gov/earth-observer-archive.

This sad news for NASA comes as the pandemic resulting from novel coronavirus disease COVID-19 continues. As of this writing, all NASA Centers are now at Stage 3 in the agency's four-stage framework.² Mandatory telework continues into its sixth month for most employees, although mission-essential, some mission-critical, and a few other health and safety-related activities are permitted to resume on site.

The Earth Observer reported in our last issue on NASA's efforts to document the impacts of COVID-19 via remote sensing with the funding of the first several Rapid Response and Novel Research in Earth Science (RRNES) science investigations.³ NASA has also entered into a partnership with the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA) to create a COVID-19 dashboard (eodashboard.org) that brings the collective Earth-observing capabilities of the three space agencies together to document planet-wide changes in the environment and human society resulting from COVID-19. The wealth of these agencies' combined information now is available at the touch of a finger. To learn more, see the News story on page 28 of this issue.

Despite the ongoing challenges posed by the pandemic, current and upcoming Earth Science missions continue to make progress.

The Copernicus Sentinel-6 Michael Freilich satellite remains on schedule for a November 10 launch. And while the altimeter community awaits this joint U.S.–European satellite, it simultaneously mourns the loss of its namesake.

“We miss him,” said **Josh Willis** [NASA/JPL—*Sentinel-6 Michael Freilich Project Scientist*]. “We wish he could have been here for the launch. But each time we make a new discovery or unravel a new mystery with data from this satellite, we'll remember Mike.”

Sentinel-6 Michael Freilich (followed by Sentinel-6B, planned to launch in 2025) will add another decade to the nearly 30-year sea-level time series that began in 1992 with the launch of the TOPEX/Poseidon mission and has continued with three more missions over the years: Jason-1, the Ocean Surface Topography Mission (OSTM)/Jason-2 (Jason-2 hereinafter), and Jason-3. In January, at the ceremony formally changing the name of Sentinel-6A to Sentinel-6 Michael Freilich, Mike described this sea-level time series as “the longest—and most successful—multinational and intercontinental, collaborative Earth remote sensing endeavor that our species has achieved.” Turn to the News story on page 30 of this issue to learn more about the status of Sentinel-6.

Meanwhile, the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission has cleared several major mission milestones within its critical design phase in late 2019 and early 2020, along its path to a planned spring 2023 launch. PACE represents NASA's next

² View the framework at <https://go.nasa.gov/31hUJe9>.

³ See “The Editor's Corner” of the May–June 2020 issue of *The Earth Observer* [Volume 32, Issue 3, p. 1—<https://go.nasa.gov/2QcDTH0>].

advance in the combined study of Earth's ocean–atmosphere–land system. The mission passed its mission-level Critical Design Review (CDR) in February 2020; it also awarded its launch vehicle contract to SpaceX. Its primary instrument—the Ocean Color Instrument (OCI)—passed its CDR in December 2019 and completed a system-level engineering test unit (ETU) thermal vacuum campaign in March 2020. OCI is a hyperspectral scanning radiometer that will measure reflected light from the near ultraviolet through near infrared, coupled with a multiband filter spectrograph to extend coverage into the shortwave infrared. It will be used to study phytoplankton as well as atmospheric aerosols and clouds. OCI is being built at GSFC.

PACE will also carry two multiangle polarimeters dedicated to aerosol and cloud science. The Spectropolarimeter for Planetary Exploration (SPEXone) will be built and overseen by the SRON Netherlands Institute for Space Research and Airbus Defence and Space Netherlands. The Hyper-Angular Rainbow Polarimeter (HARP2) will be built by the Earth and Space Institute at the University of Maryland, Baltimore County (UMBC). The SPEXone flight unit is currently undergoing environmental testing and will be delivered to the mission in early 2021. The HARP2 ETU continues to be developed and tested.⁴ HARP—a CubeSat version of HARP2—continues to perform well, following its November 2019 launch from the International Space Station (ISS).⁵

In a previous issue, we reported on the passivation of the Solar Radiation and Climate Experiment (SORCE) in February 2020 after more than 17 years of observations of the total solar irradiance (TSI) and spectral solar irradiance (SSI).⁶ The Total and Spectral Solar Irradiance Sensor (TSIS) now claims stewardship of the solar irradiance climate data record. Launched to the ISS in December 2017, TSIS-1 has now completed over two years of science observations—a significant portion of which overlapped with SORCE and the TSI Calibration Transfer Experiment (TCTE), which completed its science mission on July 1, 2019. The TSIS-1 total and spectral solar irradiance measurements continue to meet the high accuracy and stability requirements of a *climate data record*, a time series of measurements of sufficient length, consistency, and continuity to quantify climate variability and climate change. LASP at the University of Colorado, where TSIS-1 was built and is operated, is also flying a technology demonstration mission called the Compact

Spectral Irradiance Monitor (CSIM). This CubeSat mission was launched in December 2018 and is still flying. Data from the initial operations of CSIM were released in March 2019, showing exceptional agreement with the Spectral Irradiance Monitor (SIM) on TSIS-1.

We are happy to report that TSIS-1 operations have continued with minimal impact from the COVID-19 pandemic since mission and science operations and data processing are largely automated for routine public access. Meanwhile, in January 2020, TSIS-2 completed an important milestone by passing its CDR as it prepares for a 2023 launch date. Unlike TSIS-1 on ISS, TSIS-2 will be a free-flyer mission much like its predecessor, SORCE. In early July the contract to build the TSIS-2 spacecraft was awarded to General Atomics Electromagnetic Systems Group of San Diego, CA.⁷

Related to these missions, the lead article in this issue is a summary of the Sun–Climate Symposium meeting that took place in January 2020 in Tucson, AZ. Sessions highlighted the achievements of the SORCE mission and covered current and future observations (e.g., TSIS-1 and TSIS-2), models, solar variability, as well as discussions of the expectations for the upcoming solar cycle 25. Turn to page 4 to read more about this meeting. ■

⁷ To learn more about the status of TSIS-2, see <https://go.nasa.gov/2QkE4A5>.

List of Undefined Acronyms Used in The Editor's Corner and Table of Contents

AOGS	Asia Oceania Geosciences Society
CALIPSO	Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Operations
COVID-19	2019 Novel Coronavirus Disease
CERES	Clouds and the Earth's Radiant Energy System
GSFC	NASA's Goddard Space Flight Center
JPL	NASA/Jet Propulsion Laboratory
LASP	Laboratory for Atmospheric and Space Physics

⁴ To learn more about PACE, visit <http://pace.gsfc.nasa.gov>.

⁵ To learn more about HARP's achievements, see “The Editor's Corner” of the May–June 2020 issue of *The Earth Observer* [Volume 32, Issue 3, p. 2].

⁶ See “The Editor's Corner” of the March–April 2020 issue of *The Earth Observer* [Volume 32, Issue 2, p. 3].

Summary of the 2020 Sun–Climate Symposium

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The unique theme of the symposium was: "What Is the Quiet Sun and What Are the Subsequent Climate Implications?"

Introduction

Observations of the Sun and Earth from space have revolutionized our view and understanding of how solar variability and other natural and anthropogenic forcings impact Earth's atmosphere and climate. For more than four decades (spanning four 11-year solar cycles and now beginning a fifth), the total and spectral solar irradiance and global terrestrial atmosphere and surface have been observed continuously, providing an unprecedented, high-quality time series of data for Sun–climate studies—see **Figure 1** on the next page.

Sun–Climate Symposia, originally called Solar Radiation and Climate Experiment (SORCE) Science Team Meetings, have been held at a regular cadence since 1999—even before the launch of SORCE in 2003. The 2020 Sun–Climate Symposium was held at the University Park Marriott in Tucson, AZ, January 27–31, 2020. (This sixteenth meeting in the series occurred one month prior to the decommissioning of SORCE.) The Sun–Climate Research Center—established as a collaboration between NASA's Goddard Space Flight Center (GSFC) and the Laboratory for Atmospheric and Space Physics at the University of Colorado (LASP/CU Boulder, hereinafter referred to as LASP)—organized the symposium. The unique theme of the symposium was: *What Is the Quiet Sun¹ and What Are the Subsequent Climate Implications?*

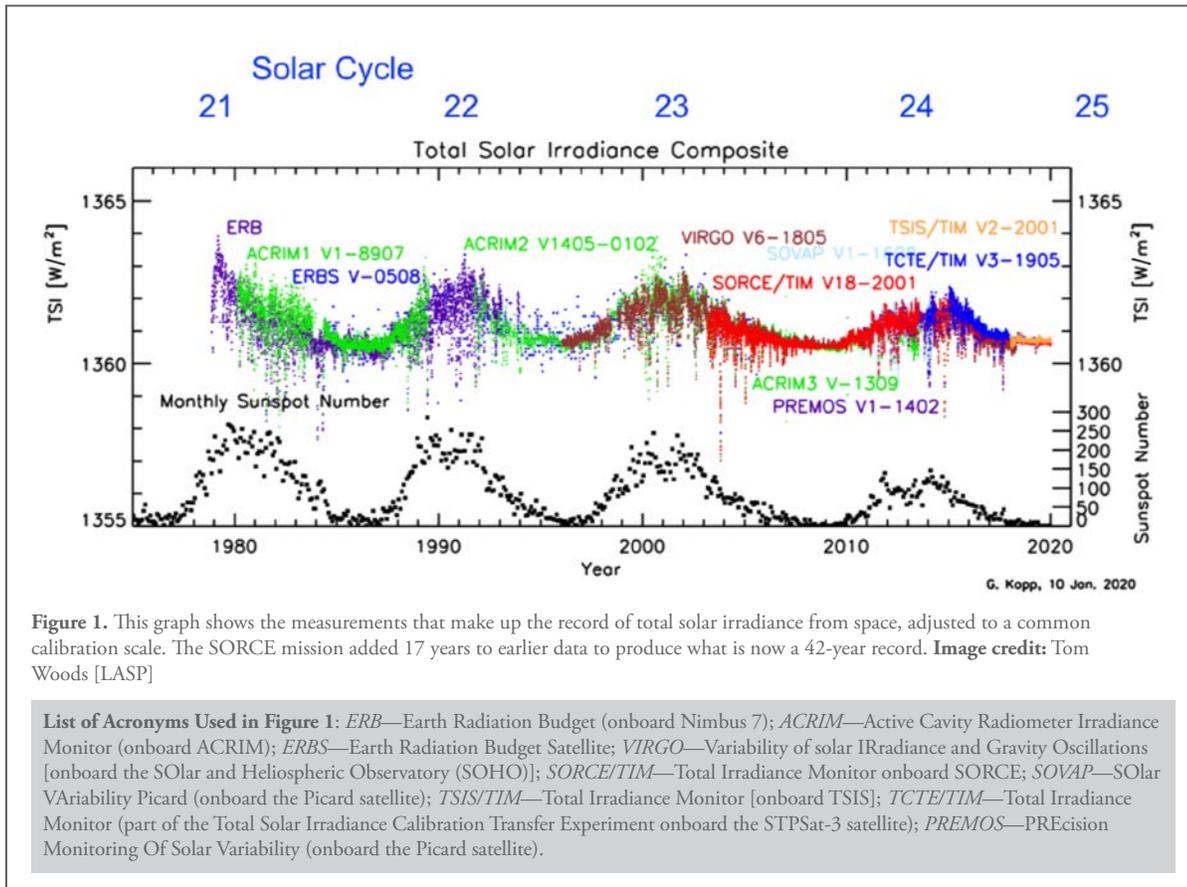
The symposium convened experts from across the solar–terrestrial community, including the disciplines of climate research, atmospheric physics and chemistry, heliophysics, and metrology, to discuss solar and climate observations and models over both spacecraft-era and historical timescales. Altogether, 89 scientists and students from around the world gathered to present their findings and to engage in spirited discussions—see photo below. One presentation was presented remotely.



Attendees at the 2020 Sun–Climate Symposium in Tucson, AZ. **Photo credit:** Kelly Hepburn [LASP]

The meeting consisted of seven oral sessions, a poster session, and an optional tour of two world-class laboratories at the University of Arizona—see *Sun–Climate Symposium Attendees Visit Prestigious University of Arizona Labs* on page 11. The first of the

¹ Quiet Sun refers to the Sun at the minimum of solar activity during its 11-year cycle.



oral sessions highlighted SORCE achievements. The remaining sessions (including the posters) covered current solar variability, future solar and climate observations, models, as well as discussions of the expectations for the next solar cycle. Most of the 2020 Sun–Climate Symposium presentations are available online at <https://tinyurl.com/yahd2yz3>.

Meeting Overview

The 2020 Sun–Climate Symposium coincided with the transitional phase between the end of solar cycle 24 and the onset of cycle 25, a period known as *solar minimum*, when the Sun is relatively “quiet.” As a result, the meeting’s content was organized around these guiding questions:

- What exactly is the *quiet Sun*? Is it a time-invariant base level or is there variability in the Sun’s radiative output over centennial-to-millennial time scales?
- What do those alternate scenarios imply for Earth’s climate responses?

The meeting also coincided with a transitional period in the availability of observational tools to monitor the solar radiative input to the Earth system. The SORCE science mission ended just four weeks after the start of the symposium—on February 25, 2020. And last summer, on June 30, 2019, the Total Solar Irradiance Calibration Transfer Experiment (TCTE) mission ended.² Therefore, stewardship of the solar irradiance climate data record is now fully in the domain of the

² TCTE launched in 2013 on the U.S. Air Force Space Test Program spacecraft known as Space Test Program (STPSat)-3, a mission designed to assess sensors for military needs.

The 2020 Sun–Climate Symposium coincided with the transitional phase between the end of solar cycle 24 and the onset of cycle 25, a period known as solar minimum, when the Sun is relatively “quiet.”

The 2020 Symposium kicked off with a special session to highlight many of the SORCE mission accomplishments, discoveries, and lessons learned during its 17-yearlong mission.

Total and Spectral Solar Irradiance Sensor (TSIS). TSIS-1 launched in 2017 and is currently mounted on ExPRESS Logistics Carrier 3 (ELC 3)³ on the International Space Station (ISS). TSIS-2 is in development and is currently scheduled for a 2023 launch on a still-to-be-determined, free-flying satellite⁴ with a planned three-year mission lifetime. The two instruments on TSIS-2, the Total Irradiance Monitor (TIM) and Spectral Irradiance Monitor (SIM), will be identical to those on TSIS-1 and are being developed at LASP.

Opening Remarks

During the 2018 Sun–Climate Symposium, **Peter Pilewskie** [LASP—*TSIS-1 Principal Investigator (PI)*] and **Tom Woods** [LASP—*SORCE PI*] symbolized the connection between SORCE and TSIS with a relay baton being passed from SORCE to TSIS.⁵ In the nearly two years since that meeting, SORCE has steadfastly refused to relinquish its grip on the baton: Despite a recurrence of battery problems that had plagued SORCE for years, initially triggering an acceleration of the SORCE decommissioning plan, NASA decided to extend SORCE operations first into January and then February 2020. In their opening remarks, Pilewskie summarized highlights from the first two years of TSIS-1, while Woods recapped the achievements from SORCE during its remarkable 17 years in orbit.

Session 1: The Sunset of SORCE

The 2020 Symposium kicked off with a special session to highlight many of the SORCE mission accomplishments, discoveries, and lessons learned during its 17-year-long mission.⁶ Among the key SORCE results are the improved climate records of the total solar irradiance (TSI) and solar spectral irradiance (SSI), with measurements from the SORCE TIM, SIM, SOLar-STellar Irradiance Comparison Experiment (SOLSTICE), and Extreme Ultraviolet (XUV) Photometer System [XPS] instruments.

Gary Rottman [LASP—*Original Principal Investigator for SORCE from 1999–2006*] started the session with a history of the mission beginning in 1988 with LASP’s original

SORCE can only be regarded as a highly, highly successful mission. It has achieved great scientific results, it has far outlived its intended mission life, and it has stayed well below all cost guidelines. Small free-flying spacecraft are the ideal and very best way of making solar irradiance observations as illustrated first by the Solar Mesosphere Explorer [1981–1989] and now by SORCE [2003–2020]. For both of these missions LASP and the University of Colorado excelled in managing the programs put in place by the PI and keeping the science objectives as the guiding principle—all the while training students, young scientists, and engineers, and returning exceptional value to NASA. TSIS-1 continues the observations of SORCE, with similar great instruments, albeit with restricted observations from ISS. TSIS-2 [will carry] on the “free-flying” tradition, although it will have a very different mission and management structure.

— **Gary Rottman**, Original SORCE PI [1999–2006]

proposal to NASA’s Earth Observing System (EOS) to provide a SOLSTICE instrument to measure the solar UV irradiance. Over the intervening years before the SORCE launch in 2003, the mission evolved to include two additional spectral instruments that measured almost all wavelengths from the shortest X-rays through a good portion of the shortwave infrared (IR) and a new instrument concept to revolutionize the measurement of TSI. Rottman discussed the many twists and turns of fate, some planned and some not, that expanded SORCE to its full capability. He was followed

by **Bob Cahalan** [GSFC, *retired—SORCE Project Scientist from 1999 to 2015*], who provided his personal and professional reflections on the build and launch of SORCE.

³ ExPRESS stands for Expedite the Processing of Experiments to the Space Station; ExPRESS Logistics Carriers (ELCs) are unpressurized attached payload platforms for the International Space Station.

⁴ **UPDATE:** In July 2020, NASA announced that General Atomics Electromagnetics Group of San Diego, CA, has been chosen to build the TSIS-2 spacecraft.

⁵ To learn more about the previous meeting, read the “Summary of the 2018 Sun–Climate Symposium” in the May–June 2018 issue of *The Earth Observer* [Volume 30, Issue 3, pp. 21–26—<https://go.nasa.gov/3fRUOdm>]. The “baton” is pictured on page 22 of that issue.

⁶ The significant accomplishments from the first 10 years of SORCE were summarized in “The SORCE Mission Celebrates Ten Years” in the January–February 2013 issue of *The Earth Observer* [Volume 25, Issue 1, pp. 3–13—<https://go.nasa.gov/3kGaqTQ>].

Greg Kopp [LASP—*SORCE*, *TCTE*, and *TSIS TIM Instrument Scientist*] described the TIM instrument, noting the many innovations in its design that led to improved accuracy and precision over previous instruments. He presented a long list of TIM accomplishments and how its measurements compared to those from other past and current instruments.

Jerry Harder [LASP—*SORCE SIM Instrument Scientist*] followed with highlights from the *SORCE SIM* instrument, the first to provide an uninterrupted record of daily solar variability at visible and IR wavelengths. Along with the ultraviolet (UV) part of the spectrum acquired by SIM, this represents 97% of the total solar output. Harder discussed the importance of SIM measurements to solar activity and climate modeling, and the technological advances incorporated into the design of SIM that have been passed on to the next generation of solar-spectral radiometers.

Marty Snow [LASP] reported on 17 years of SOLSTICE measurements of SSI from 115 to 300 nm. In addition to providing a new understanding of short- and long-term variability in the UV, *SORCE SOLSTICE* observations have been used to derive a Magnesium II Core-to-Wing Index. The so-called Mg II index is an important proxy for solar activity since it is highly correlated with solar extreme UV radiation (10–124 nm), which makes it important for understanding physical processes in Earth's upper atmosphere. Snow noted that SOLSTICE measurements have also been used to calibrate solar irradiance models, to calibrate other solar measurements, and to construct reference solar spectra.

Tom Woods summarized *SORCE XPS* observations of X-ray UV (1–34 nm) and the neutral hydrogen HI Lyman- α (121.6 nm) solar irradiance. One key finding showed that irradiance at the shortest wavelengths varies over the solar cycle by more than a factor of 10 and it varies by a factor of 1.7 for HI Lyman- α . Additionally, XPS observed more than 3000 flares during the *SORCE* mission, with the largest occurring in October–November 2003, during solar cycle 23, and in September 2017, during solar cycle 24.

Sean Ryan [LASP—*SORCE Mission Operations*] described the many challenges in managing *SORCE* flight operations. Perhaps the most notable was the extreme degradation in battery capacity that required redesigning the way the spacecraft was operated in 2014. As the capacity of the battery decreased, instruments were phased out of operations in *eclipse* (i.e., when Earth blocks *SORCE* from viewing the Sun) while strategies were tested to improve battery performance and longevity. By 2014 *SORCE* began to operate in daylight-only mode, and cleverly designed automation sequences allowed the mission to continue despite greatly reduced battery capacity.

The session closed with **Tom Sparn** [LASP—*Original SORCE Program Manager*] giving a retrospective view of the highly collaborative relationship between GSFC *SORCE* management, LASP, and Orbital Sciences Corporation (OSC), which built

It is indeed a pleasure to recall being SORCE project scientist, through the build, the January 2003 launch, the 2003 Halloween X-rays, the 2008 “Great Minimum” during the “Great Recession,” the TSI evolution from “Outlier” to “Gold Standard,” the 2004 and 2012 dual Venus transits, the 2013 “gap year,” the 2013–2014 double-peaked solar maximum, the flip-flop “DO-Op” mode, witnessing the fitful winding down of cycle 24, the beautiful 17-year record of the TSI, and the first-ever ultraviolet–visible–near infrared record of daily SSI variations. Though I retired as project scientist in 2015, I continue to enjoy and applaud successes such as the December 2017 TSIS-1 launch that enabled a full two-year SORCE–TSIS-1 overlap, which ended with the bittersweet moment of SORCE’s “sunset” or “passivation” in February 2020. And now, as solar cycle 25 begins, TSIS-1 takes the baton and Sol begins cycle 25, I want to thank all who have been involved, as mission success has relied in essential ways on many varied contributions by all.

— **Bob Cahalan**, *SORCE* Project Scientist [1999–2015]

The SORCE mission has provided an excellent dataset of total solar irradiance and solar spectral irradiance for the past 17 years, and this exceeds all of my expectations for the planned five-year mission. The last seven years have been particularly remarkable as SORCE has operated with a very unhealthy battery and still was able to have normal solar observations, thanks to the dedication and creative solutions by the SORCE operations team.

— **Tom Woods**, *SORCE* PI [2006–present]

and integrated the spacecraft. Sparn discussed how management processes brought the implementation of the SORCE mission to its successful conclusion, on schedule and within budget. It was the outstanding relationship between the academic, government, and industry partners that enabled the success of SORCE.

Session 2: Recent and Spacecraft-Era Solar-Cycle Timescales

This session, beginning with the start of the “spacecraft era” for Sun and Earth observations in the late 1970s, was devoted to solar measurements and models covering the last few solar cycles. Particular emphasis was placed on current understanding of the quiet Sun. There were several presentations

on SSI and spectral variability. New data from the TSIS-1 SIM were presented, along with comparisons of TSIS-1 data to other measurements and modeled spectral irradiance, and a quantitative analysis with SORCE SIM during the SORCE/TSIS-1 overlap period.

Serena Crisculi [National Solar Observatory] gave an invited presentation on “Modern and Historical Reconstructions of Solar Ultraviolet (UV) Irradiance Variability.” The hybrid reconstruction method she described combines semi-empirical and proxy models with data assimilation of sunspot number, full-disk observations, and modern UV-irradiance measurements by SORCE.

After the invited presentation, the focus of the session shifted from UV to TSI measurements. One presentation featured new results from the Compact Lightweight Absolute Radiometer (CLARA),⁷ along with comparisons between CLARA data and contemporaneous TSI observations. Other TSI-focused presentations considered a three-point differencing technique to quantify the precision in VIRGO,⁸ SORCE, TCTE, and TSIS-1 measurements, and the quantitative comparison between SORCE and TSIS-1 TSI data.

Understanding how TSI measurements have varied in the past relies on sophisticated solar *proxy models* that connect modern measurements of solar irradiance to features on the Sun that have been measured for centuries. Some presentations during this session detailed the progress that has been made with the development of new methods to construct coherent time series that are tied to the latest calibration scales. Additional improvements in solar irradiance reconstructions from solar proxy models may be achieved by the use of linear transfer functions that assume convolutional rather than instantaneous relationships between the proxy and solar irradiance.

Bo Andersen [Norwegian Space Agency] gave an invited presentation, during which he delivered a moving homage to Claus Fröhlich, who is one of the modern giants in the measurement of solar irradiance, former director of Physikalisch-Meteorologisches Observatorium Davos (PMOD), and an original member of the SORCE Science Team—see *In Memoriam: Claus Fröhlich [1936–2019]* on page 9.

The tremendous success of the SORCE program management started with establishing a true partnership with the three principal participants: LASP, NASA, and Orbital Sciences, [representing] academia, government, and industry. This partnership was the cornerstone on which a relationship of trust was formalized with clear, well-defined contracts that acknowledged the acceptance of shared risk by all partners. This successful relationship leveraged trust, mutual support, leadership, focused goals, defined requirements, science buy-in, and consistent financial support throughout the mission, from the start of Phase A to the conclusion of Phase E. The free and open communication fostered by this relationship allowed for optimal solutions to be accomplished and brought the mission success.

— **Tom Sparn**, LASP SORCE Program Manager [1999–2009]

It was the outstanding relationship between the academic (LASP), government (GSFC), and industry (OSC) partners that enabled the success of SORCE.

⁷ CLARA flies on the Norwegian satellite NORSAT-1, a nanosatellite launched in 2017.

⁸ VIRGO stands for Variability of solar IRradiance and Gravity Oscillations; it flies on the European Space Agency–NASA SOLar and Heliospheric Observatory (SOHO) that launched in 1998. The instrument is the result of an international collaboration by several European countries.

In Memoriam: Claus Fröhlich [1936–2019]

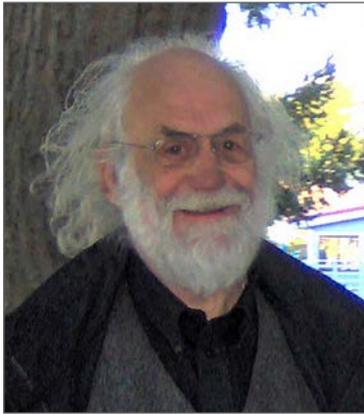


Photo credit: Vanessa George [LASP]

Claus Fröhlich passed away on February 22, 2019. He put his heart and soul into his solar research and was one of the original co-investigators on SORCE. He led several key solar missions in Europe and was very important in contributing to the continuation of the long-term solar irradiance data record. To view his full In Memoriam, see <https://www.sps.ch/en/archive/nachrufel/in-memoriam-claus-froehlich>.

Session 3: Solar Variability and Climate Trends on Secular Timescales

This session focused on the following questions:

- What have we learned about the ranges of total and spectral solar irradiance variability?
- What are the trends in proxies of solar activity and paleoclimate records, such as tree rings and cosmogenic isotopes, on multidecadal-to-millennial timescales?
- What are the potential secular trends in the Sun, based on trends observed in other stars?
- What are the associated impacts on Earth's climate that are estimated from these records?

A key physical phenomenon that underlies much solar behavior of interest is the *solar dynamo*, which generates a magnetic field in the interior of the Sun that travels through the convective zone and emerges on the solar surface, leading to various manifestations of solar magnetic activity, including variations in solar brightness. Much progress has been made in understanding solar variability on timescales ranging from hours to millennia, and recent observations of Sun-like stars younger than the Sun have been used successfully to reconstruct solar activity and brightness variability over the last four billion years.

Considering only the last four centuries, the sunspot record is the longest continuous, directly observed solar record in existence. Creating a composite sunspot record by merging the many hundreds of observations that contribute to the record requires corrections for offsets, trends, and nonlinearities in the individual time series. Sunspot numbers are collated by the World Data Center (WDC) Sunspot Index and Long-term Solar Observations (SILSO) Version 2.0 at the Royal Observatory of Belgium. But a new group sunspot number composite is the result of testing several new composite-creation methods and recovering and updating many historical sunspot records. These revisions produce a sunspot record that differs from prior versions with expected impacts on several solar phenomena and historical TSI reconstructions.

In addition to looking at the Sun's activity over time, we also look to other stars to gain insight into the behavior of our own Sun. Missions like Kepler and the Transiting Exoplanet Survey Satellite (TESS) have enabled *asteroseismology* (study of the internal structure of stars by the interpretation of their frequency spectra as they correlate with oscillation modes at different depths) and measurement of star-spot modulation for a

Creating a composite sunspot record by merging the many hundreds of observations that contribute to the record requires corrections for offsets, trends, and nonlinearities in the individual time series.

There is evidence that middle-aged stars undergo a transition in their magnetic properties, manifested by changes in their rotational behavior and magnetic activity. “The question remains: What are the implications for our own middle-aged star, the Sun?”

multitude of stars. These datasets have enabled examination of the link between stellar rotation and magnetism observed in the Sun, facilitating the study of stars in various phases of their evolution. There is evidence that middle-aged stars undergo a transition in their magnetic properties, manifested by changes in their rotational behavior and magnetic activity. The question remains: *What are the implications for our own middle-aged star, the Sun?*

Stars also provide a means to judge the state of the quiet Sun. By collecting large samples of stellar observations, it is possible to determine a lower activity level among solar-type stars. This facilitates the extrapolation of observed solar activity to even “quieter” levels, to examine consequences of the Sun in its quietest possible state.

Valerie Trouet [Laboratory of Tree-Ring Research, University of Arizona] focused on a very different dataset in her presentation titled “Reduced Caribbean Hurricane Activity During the Maunder Solar Minimum.” Trouet combined a time series documenting Spanish shipwrecks in the Caribbean (1495–1825 CE) with a tree-growth suppression chronology from the Florida Keys (1707–2010 CE) to find a 75% reduction in decadal-scale North Atlantic tropical cyclone (NATC) activity during the *Maunder Minimum*.⁹ These results emphasize the need to enhance our understanding of the responses of oceanic and atmospheric circulation patterns to radiative forcing and climate change in order to improve the skill of future NATC projections.

Session 4: Solar Influence on the Atmosphere and Climate

This session was devoted to the measured and modeled responses of Earth’s atmosphere and climate to solar variability over the last few solar cycles. **Judith Lean** [Naval Research Laboratory, *retired*] gave a keynote presentation on “Navigating the Causes of Modern Climate Change.” One challenge she addressed was the so-called “global warming hiatus” from 2000 to 2015, when global surface temperatures increased less rapidly than during the last half of the twentieth century, despite the continued increase in greenhouse gas concentrations. The suggestion that “missing” mechanisms are influencing climate exacerbated confusion among policy makers, the public, and other stakeholders about the causes and reality of modern climate change. Lean presented a statistical analysis of surface-temperature observations for a quantitative interpretation of modern climate change as a mix of both anthropogenic and natural influences, including the Sun’s irradiance cycle.

Perhaps the most easily detectible solar influence on Earth’s atmosphere is the response of ozone concentration in the middle atmosphere to solar UV variability, as changes in ozone concentrations can influence dynamical processes in both the troposphere and the stratosphere. Decreases in stratospheric ozone have been linked to stratospheric cooling trends and increases in the strength of the *Brewer–Dobson* (ozone) *circulation*¹⁰ in the lower stratosphere, while—at the surface—the largest climate impacts are in the Southern Hemisphere summer. These climate impacts are expected to reverse over the coming decades as stratospheric ozone recovers due to the actions taken to dramatically reduce ozone-depleting chemicals as a result of the 1987 Montreal Protocol. The relative importance of ozone recovery for future Southern Hemisphere climate will depend on the evolution of atmospheric greenhouse gas concentrations.

⁹ The Maunder Minimum, a.k.a., the prolonged sunspot minimum, is the name given to a period of extremely slow solar activity (e.g., sunspots) that lasted from 1645 to 1710. The term Maunder Minimum was first used in a 1976 landmark paper by John C. Eddy to honor the work of Annie Russell Maunder [1868–1947] and her husband, Edward Walter Maunder [1851–1928], who studied how sunspot latitudes changed with time.

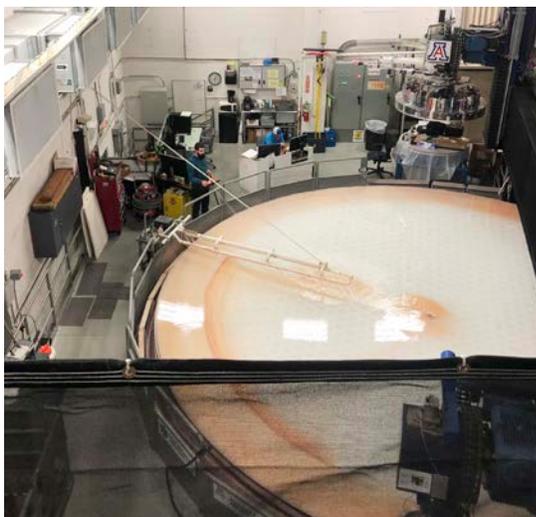
¹⁰ The Brewer–Dobson circulation is an atmospheric circulation that explains why there is less ozone in the tropics than at the poles—even though more ozone is produced in the tropical stratosphere. The model posits the existence of a slow current in the winter hemisphere that redistributes air from tropics to extratropics. It is named after Alan Brewer and Gordon Dobson who proposed the theory in 1949 and 1956, respectively.

Sun–Climate Symposium Attendees Visit Prestigious University of Arizona Labs

On the afternoon of the second day, symposium attendees had the opportunity to tour the Richard F. Caris Mirror Laboratory and the Laboratory of Tree-Ring Research at the University of Arizona.

Richard F. Caris Mirror Laboratory

Participants were privileged to listen to a lecture on the history of the Richard F. Caris Mirror Laboratory and to view the facilities where the complex fabrication occurs, where a team of scientists and engineers are making giant, lightweight mirrors of unprecedented power for a new generation of optical telescopes. During the tour, the participants learned that—unlike conventional solid-glass mirrors—the mirrors produced at the Laboratory have an internal honeycomb structure, so they can be made significantly larger and dramatically lighter than other mirrors. The mirrors are made out of Ohara E6-type borosilicate glass that is melted, molded, and spun cast into the shape of a paraboloid in a custom-designed rotating oven. The Laboratory continues its impressive history of successful, groundbreaking mirror castings with its work on the Giant Magellan Telescope being built by an international consortium at its location in the Las Campanas Observatory in Chile. When completed, this telescope will be the largest and most advanced Earth-based telescope in the world. Currently, five of the seven 8.4-m (27.6-ft) segmented mirrors have been cast. The first mirror is complete and the other four are in various stages of production.



During the tour of the University of Arizona's Richard F. Caris Mirror Laboratory, participants got to see one of the massive mirrors being built for the Giant Magellan Telescope, which will be the largest Earth-based telescope in the world. **Photo credit:** Marty Snow [LASP]

Laboratory of Tree-Ring Research

The other tour was of the Laboratory of Tree-Ring Research (LTRR), which was created in 1937 by Andrew Ellicott Douglass to study tree rings in America. Since its founding, LTRR has helped establish many *dendrochronology* labs to date and conducted studies of annual rings in trees around the world. During the tour, participants learned that scientists use tree rings to answer questions about the natural world in order to put the present in proper historical context; to better understand current environmental processes and conditions; and to improve understanding of possible future environmental issues. Ring counting alone does not ensure the accurate dating of each individual ring, which can lead to incorrect conclusions. One of the techniques used by the LTRR is *cross-dating** to match ring growth characteristics across many samples. Through their work, LTRR is making significant contributions to understanding natural variability in climate including hydrologic, geomorphic, and ecological systems.

*Cross-dating is a basic technique used in dendrochronology that ensures each individual tree ring is assigned its exact year of formation by matching patterns of wide and narrow rings between cores from the same tree, and between trees from different locations.



During the tour of the University of Arizona's Laboratory of Tree-Ring Research, participants got a chance to get a close-up view of the tree rings on this cross section from a giant sequoia. **Photo credit:** Marty Snow [LASP]

Solar spectra are widely used by the modeling and remote sensing communities as the solar input constraint.

Solar UV variability may also play an influential role in the *Madden–Julian Oscillation*.¹¹ In addition, a new model study shows that sustained low solar forcing leads to complex changes in both atmospheric and oceanic circulations. The expected surface cooling under such conditions occurs at different rates between the two hemispheres, the result of which is to generate atmospheric waves. The results provide further evidence of the importance of atmosphere–ocean coupling in Sun–climate connections.

Christopher Castro [University of Arizona, Tucson] wrapped up the session with a local flair as he discussed a topic relevant to Arizona: the “North American Monsoon in a Changing Climate.” He showed that North American monsoon precipitation associated with organized convection is becoming less frequent and more extreme. Such changes are broadly consistent with how extreme precipitation is changing globally during the current warming world.

Session 5: A New Reference Spectrum for Remote Sensing

Solar spectra are widely used by the modeling and remote sensing communities as the solar input constraint. Uncertainties associated with solar spectral measurements can have significant impacts on theoretical and experimental topics ranging from upper atmospheric photochemistry to the full system radiation budget. They also have an impact on techniques that use the Moon as a solar-reflectance calibration standard. Improved accuracy in solar spectral irradiance measurements has opened the possibility of achieving *Système Internationale d’Unités-traceable* lunar radiometry. However, as with many applications in remote sensing and global energy budget assessments, this technique requires higher resolution than the directly measured solar-irradiance spectra. Some presenters during this session discussed implications of the improved accuracy of solar-irradiance spectra from TSIS-1 SIM. Others highlighted the need for new solar-reference spectra and current progress toward that goal.

The Global Space-based Inter-Calibration System (GSICS), an international organization designed to promote calibration best practices across satellite dataset providers, has long recognized the need for a common solar reference spectrum to maintain consistency in band radiances among the many sensors used in Earth remote sensing from space. GSICS is working to promote a recommended solar spectrum used by all dataset providers. **Dave Doelling** [NASA’s Langley Research Center] provided background on community needs and requirements for a common reference spectrum by looking at sensor band radiance differences based on several widely used solar spectra.

One example of the sensitivity of satellite remote sensing applications to solar spectral irradiance input came from the Orbiting Carbon Observatory–2 (OCO-2), which measures reflected shortwave-IR solar radiation carbon dioxide (CO₂) and methane (CH₄) concentrations. For OCO-2, the solar spectrum provides an in-orbit radiometric and spectroscopic calibration standard that is used in retrieval algorithms for estimating the column-averaged mole fractions of CO₂ and CH₄, denoted as X_{CO₂} and X_{CH₄}, respectively. Although the newly implemented TSIS-1 solar spectrum showed significant differences from the previously used ATLAS 3 SOLSPEC¹² spectrum, the associated changes in retrieved X_{CO₂} were less than 0.3%, but were positive over land and negative over water. Consequently, these changes may still be important for source–sink inversion studies due to their spatial distribution.

From the realm of ground-based remote sensing, the AERosol RObotic NETwork (AERONET) is also being used to examine potential changes in its remotely sensed products as a result of a new, higher-accuracy reference spectrum from TSIS-1 SIM. AERONET is a global ground-based sunphotometer network for characterizing

¹¹ The Madden-Julian Oscillation (MJO) is the major source of fluctuation in tropical weather on weekly to monthly timescales. The MJO can be characterized as an eastward moving “pulse” of clouds and rainfall near the Equator that typically recurs every 30 to 60 days.

¹² SOLSPEC stands for Solar Spectrum spectrometer, which flew with the Atmospheric Laboratory for Applications and Science (ATLAS) on the Space Shuttle.

aerosol optical, microphysical, and radiative properties at approximately 600 sites supporting satellite aerosol retrieval assessments and global aerosol model validation research; the top-of-atmosphere solar spectra play a key role in the creation of the AERONET database.

In addition to these applications of the new TSIS-1 solar spectrum, work is underway to combine high-resolution solar transmittance spectra with the high-accuracy but low-resolution measured spectra to maintain the irradiance calibration scale at high resolution. The promising results from these studies will broaden the impact of high-accuracy TSIS-1 spectra to a myriad of remote sensing and radiative transfer applications.

Session 6: Observational Predictions

This session addressed these questions:

- What are expectations for the next solar cycle and what are climate-change scenarios for the upcoming decades?
- What future measurements are expected to improve knowledge of Sun–climate connections?

Dean Pesnell [GSFC] asked, “How Well Can We Predict Solar Cycle 35?” This symposium takes place during the transition period between the fading solar cycle 24 and the start of solar cycle 25, the signs of which are beginning to appear at the solar surface. Data from NASA’s Solar Dynamics Observatory (SDO) and the Solar Terrestrial Relations Observatory (STEREO) had improved predictions of solar activity during solar cycle 24 on time scales ranging from days to more than a year. But predictions made long before the next cycle begins still rely on precursors. Longer-term predictions—say, ten cycles out, as the title suggests—are limited by the growth of the forecast error, which increases until a simpler forecast becomes more accurate. The climatological average is the only long-term prediction whose error grows slowly. The consensus among participants was that accurate, long-term forecasting should adopt an ensemble format.

Philip Judge [National Center for Atmospheric Research, High Altitude Observatory] attempted to predict the future, as his presentation considered the “Next Five Decades Under the Sun.” At decadal-to-millennial time scales, solar variations that are induced by hydromagnetic effects can be constrained by solar and stellar data in the absence of credible models based upon first principles. New solar and stellar observatories combined with machine learning methods may enable the present generation of scientists to predict with a higher degree of confidence the solar–terrestrial effects that are of concern to modern society.

Session 7: Looking Ahead—Future Observations of the Sun and Earth

Presentations in this session addressed plans for the next generation of solar and terrestrial observations, missions, and implementation strategies to allow new observing systems to meet current and future challenges facing climate-change studies. One such mission is the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder mission. CLARREO Pathfinder will fly an imaging spectrometer on the ISS in 2023 to demonstrate high-accuracy measurements of the solar radiation scattered from Earth for climate-change studies and to intercalibrate other orbiting instruments.

The Sun–earth IMBAance (SIMBA)¹³ satellite is another Earth–climate demonstration mission, this one a 3U CubeSat.¹⁴ The long-term objective of SIMBA and follow-on missions is a direct measurement of Earth radiation imbalance, as SIMBA will

¹³ SIMBA is a mission developed by Belgium’s Royal Meteorological Institute (RMI) for the European Space Agency; it is scheduled for launch in 2020.

¹⁴ CubeSats (a.k.a., nanosatellites) are a class of research satellites; they are typically built to standard dimensions (Units or “U”) of 10 cm x 10 cm x 10 cm. They can be 1U, 2U, 3U, 6U, or more, in size, and typically weigh less than 1.33 kg (3 lbs) per U.

New solar and stellar observatories combined with machine learning methods may enable the present generation of scientists to predict with a higher degree of confidence the solar–terrestrial effects that are of concern to modern society.

FURST will obtain the first high-resolution, radiometrically calibrated, vacuum UV (120-180 nm) spectra of the Sun, with applications in climate science, solar and stellar physics, and the interaction of solar UV radiation with comets, moons, and planets.

*We bid you farewell,
SORCE—you won't be
soon forgotten.*

— **SORCE**
Science Team

use one instrument—a cavity radiometer—to measure incoming solar radiation and outgoing Earth radiation.

Plans are well underway for future solar irradiance measurements. The next TSIS mission, TSIS-2, will fly heritage SIM and TIM instruments, and is currently in the instrument build phase, with a scheduled launch in February 2023 on a free-flyer satellite. A Compact TIM, or CTIM, is an eight-channel, 6U, CubeSat instrument currently being built for a flight in 2021 to demonstrate next-generation technology to monitor total solar irradiance. Its cousin, the Compact SIM (CSIM), is already in orbit (since December 2018), collecting solar spectral irradiance from a 6U CubeSat. Measurements from CSIM match very well with those of TSIS SIM—see **Figure 2**.

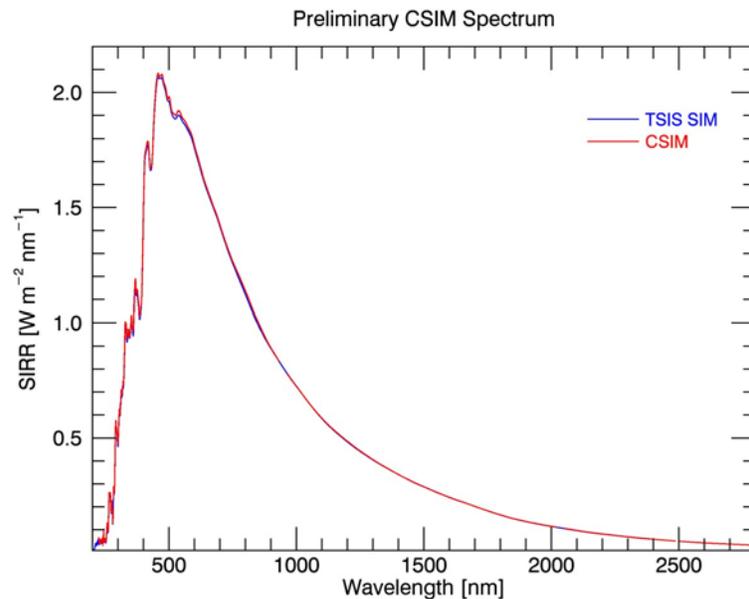


Figure 2. Comparison of solar spectral irradiance measured by TSIS SIM and CSIM. The spectra agree to better than 0.4% over the spectral range. **Image credit:** Erik Richard [LASP]

A new sounding-rocket mission, the Full-disk Ultraviolet Rocket SpecTrograph (FURST), is planned for launch in 2022. FURST will obtain the first high-resolution, radiometrically calibrated, vacuum UV (120-180 nm) spectra of the Sun, with applications in climate science, solar and stellar physics, and the interaction of solar UV radiation with comets, moons, and planets.

Conclusion

This meeting marked the sixteenth in the series of symposia that started as SORCE Science Team Meetings in 1999. It also marked the end of an era, as it was the final meeting held while SORCE was operational and still providing science data. The melancholy tone from that realization was lessened by considering that the achievements ushered in by SORCE will continue by the people who have followed in the footsteps of those who developed the SORCE mission and in the hardware (e.g., TSIS) that owes its legacy to the groundbreaking instruments developed for SORCE.

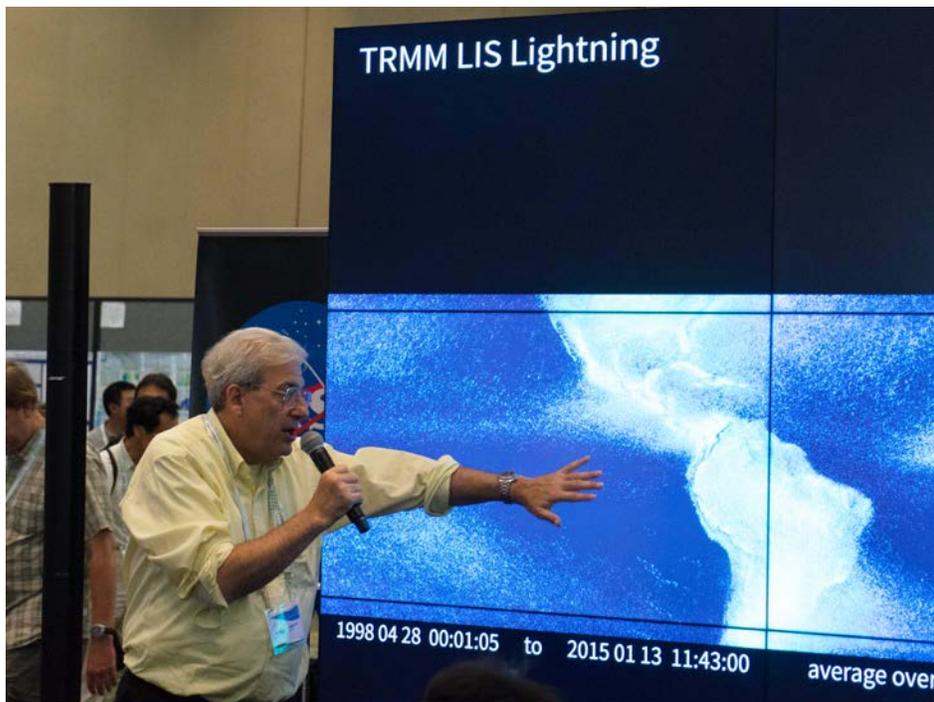
The 2020 Sun–Climate Symposium addressed the quiet Sun in the context of present-day climate change and anthropogenic and natural drivers. The multidisciplinary nature of the meeting brought together specialists in measuring and modeling the Sun’s output and Earth’s radiation budget, climate and atmospheric modelers (who interpret those and other forcings to quantify Earth’s changing environment), solar

physicists (who study how the Sun varies), and other specialists developing new instruments and missions to address some of the questions raised during the meeting. The team looks forward to the next meeting, when updates on some of the most vexing issues in Sun–Earth connections will be discussed, and new challenges are sure to be identified.

To stay up to date on the latest TSIS and SORCE news and meeting announcements, read the TSIS/SORCE newsletter at <http://lasp.colorado.edu/home/sorce/news-events/newsletter>. ■

Michael Freilich Receives 2020 Wing Ip Medal from AOGS

As reported in “The Editor’s Corner” of this issue, **Michael (“Mike”) Freilich** [Former Director of NASA’s Earth Science Division (ESD)] passed away on August 5, 2020. Prior to his passing, the Asia Oceania Geophysical Society (AOGS) announced that Mike is one of the recipients of its *Wing Ip Medal* for 2020.



Michael Freilich [Former Director of NASA’s Earth Science Division (ESD)] in front of the Hyperwall at the 2018 AOGS Annual Meeting in Honolulu, HI. **Photo credit:** NASA

Freilich was chosen because of his tireless efforts to make NASA’s Hyperwall (a nine-screen video wall) an integral part of the AOGS Annual Meeting. Since 2012 the Hyperwall has been the centerpiece of not just the NASA exhibit, but the entire conference experience, with a steady stream of eye-catching presentations to entertain and inform conference participants. The contributions of NASA scientists to the paper sessions have steadily increased over time, making a significant impact on the quality of the AOGS conferences, which in turn has helped the Society to grow in size and reputation. Freilich has been a key figure, championing the link between NASA and AOGS. His support, ambition, and charisma have been vital in developing AOGS. It is therefore most appropriate that he be awarded this prestigious medal.

The Wing Ip award was established to honor Professor Wing Huen Ip, a world-renowned astronomer. The award is given to individuals who display unselfish cooperation and leadership in geoscience in the Asia Oceania region.

The Earth Observer is pleased that Mike could receive this honor before his passing.

Summary of the Joint CALIPSO/CloudSat Science Program Annual Review

Deborah Vane, NASA/Jet Propulsion Laboratory, deborah.g.vane@jpl.nasa.gov

Introduction

The joint Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)/CloudSat Science Program Annual Review was held March 3–5, 2020—one of the last in-person NASA meetings to happen before COVID-19 shutdowns began. Ball Aerospace hosted the event at their facility in Boulder, CO. Nearly 100 scientists attended in person, with a few more participating remotely. The review was held as the fourteenth anniversary of the joint CloudSat–CALIPSO launch (April 26, 2006) was approaching—an awesome milestone for two missions built during NASA’s “faster-better-cheaper” era.¹

This report summarizes the annual review, which was broken into the following thematic sessions: Programmatic Updates, Instruments and Algorithms, Science Highlights (including presentations related to Polar Regions, Radiation and Climate, Clouds, Aerosols, and Storms and Precipitation), and Future Missions. A few highlights from each of the sessions are discussed here. The full agenda and presentations can be downloaded from <https://sites.google.com/view/ccstm-2020>.

Programmatic Updates

David Considine [NASA Headquarters (HQ)—*Program Scientist for CALIPSO and CloudSat*] welcomed the attendees and talked about the results of the 2018 Research Opportunities in Space and Earth Science (ROSES 18) CALIPSO and CloudSat Science Team (CCST) recompetition. Altogether, 101 proposals were evaluated and 21 were selected. Of those, 11 are new principal investigators (PIs) and 10 are continuing PIs. The ROSES 2021 solicitation will be released in February 2021, and funding for that ROSES call will be independent of the operational status of the CALIPSO and CloudSat satellites.

Considine then gave an overview of the President’s NASA Earth Science budget and, in that context, discussed the Aerosol and Cloud, Convection and Precipitation (ACCP) mission study and the Earth Venture Continuity (EVC) Program, both of which are

elements of the 2017 Earth Science Decadal Survey.² ACCP combines two of the five priority Designated Observable missions called out as high-priority missions by the Decadal Survey: the Aerosol (A) mission and the Clouds, Convection and Precipitation (CCP) mission. The nominal cost limit for the ACCP observing system is \$1.6B, possibly in two staggered funding wedges. The observing system will likely include both orbital and suborbital observations—see expanded discussion below.

Considine also discussed the EVC Program, the goal of which is to implement means to maintain the measurement continuity of scientifically and/or societally important observations, without undue impact on the NASA Earth Science Division (ESD) budget. The EVC-1 measurement goal is Earth radiation budget continuity, and the selected mission was Libera.³ In Roman mythology, Libera was the daughter of Ceres, so the name is an acknowledgment of the heritage of the new mission. Libera will continue the radiation balance measurements that the Clouds and the Earth’s Radiant Energy System (CERES) instruments have made for more than 20 years.⁴

Chip Trepte [NASA’s Langley Research Center (LaRC)—*CALIPSO Project Scientist*] discussed the status of the CALIPSO spacecraft. CALIPSO and CloudSat left the A-Train⁵ in 2018 and formed the C-Train—see **Figure 1** on page 17—at a lower altitude (currently ~680 km, or ~422 mi).⁶ The CALIPSO spacecraft is healthy and is satisfying all operational

² The report is called “Thriving on a Changing Planet: A Decadal Strategy for Earth Observations from Space” and is available for download at <https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth>.

³ Libera will fly on the National Oceanic and Atmospheric Administration’s (NOAA) operational Joint Polar Satellite System-3 (JPSS-3) satellite, which is scheduled to launch by December 2027. More information on Libera can be found in the “CERES Science Team Update Report” on page 24 of this issue.

⁴ Six CERES instruments are currently collecting data on NASA and NOAA satellites. A seventh flew and operated briefly on the Tropical Rainfall Measuring Mission (TRMM), which launched in 1997 and was decommissioned in 2015.

⁵ NASA and its international partners operate several Earth-observing satellites that closely follow one another along the same (or very similar) orbital “track,” called the Afternoon Constellation, or A-Train (<https://atrain.nasa.gov>).

⁶ The C-Train currently flies 16.5 km (~10 mi) below the A-Train and therefore follows a slightly different ground track, though it intersects the A-Train ground track about every 20 days, allowing for regular simultaneity between A-Train and C-Train instrument observations. Over time, the C-Train orbit is drifting eastward to later mean local times of the ascending node (i.e., it is no longer Sun synchronous).

¹ “Faster, better, cheaper” was the slogan NASA used during the 1990s, when Dan Goldin was NASA Administrator. To learn more about some of the remarkable achievements of CloudSat and CALIPSO, see “A Useful Pursuit of Shadows: CloudSat and CALIPSO Celebrate Ten Years of Observing Clouds and Aerosols,” in the July–August 2016 issue of *The Earth Observer* [Volume 28, Issue 4, pp. 4–15—<https://go.nasa.gov/2WWM2HcM>].

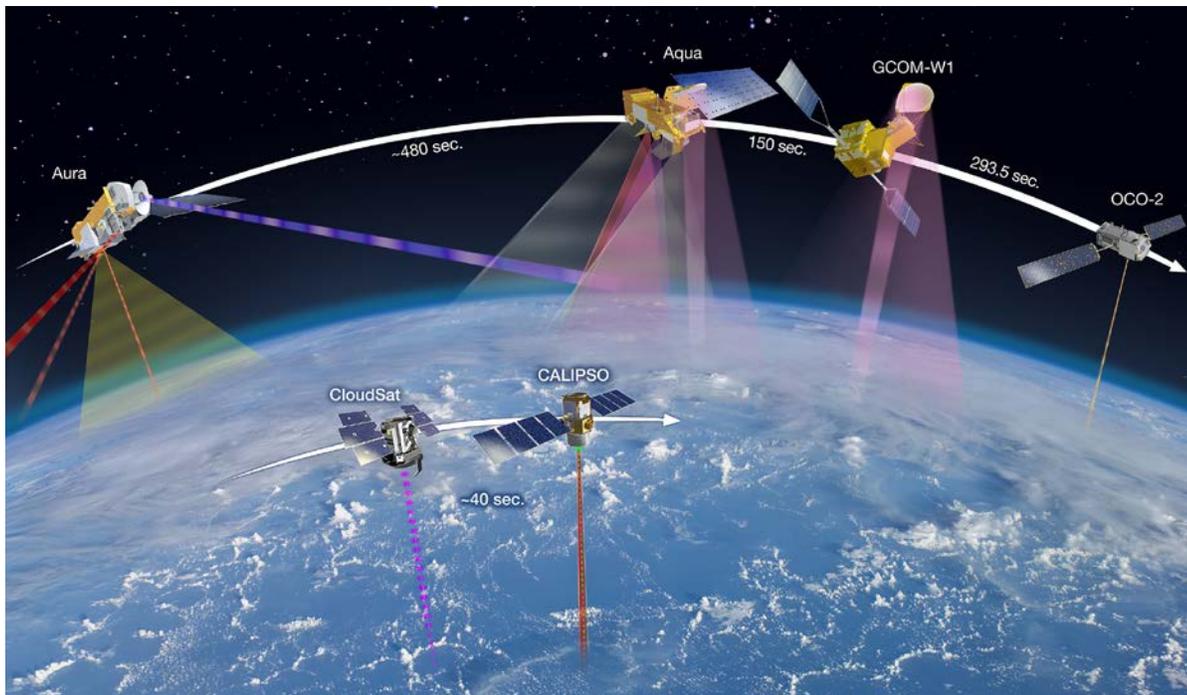


Figure 1. This diagram shows the international A-Train satellites (OCO-2, GCOM-W1, Aqua, and Aura) as well as the C-Train satellites (CALIPSO and CloudSat) at a slightly lower orbit than that of the A-Train. (GCOM-W1 stands for Global Change Observation Mission—Water, which is a Japan Aerospace Exploration Agency mission launched in 2012.) **Image credit:** NASA

requirements. Fuel reserves, however, are mostly depleted; it is possible that CALIPSO may only be able to make one additional collision avoidance maneuver.⁷ As the C-Train orbit drifts eastward, the Sun angle on the solar panels will change and, by September 2023, CALIPSO will have insufficient power to continue the mission and will begin decommissioning. The currently operating laser is still functional, despite being at pressures where corona discharges are expected for the laser Q-switch. Low-energy laser shots have been observed since mid-June 2016, mostly occurring within the South Atlantic Anomaly, but their frequency elsewhere is increasing rapidly. It is likely that the primary laser (currently not operating) will be restarted within the next year. CALIPSO has had 2853 peer-reviewed publications since launch. In 2019 alone, there was nearly the equivalent of one publication per day (363 publications).

Deborah Vane [NASA/Jet Propulsion Laboratory (JPL)—*CloudSat Project Manager*] discussed the status of the CloudSat spacecraft. CloudSat has been successfully operating in Daylight-Only Operations (DO-Op) mode since 2011. CloudSat left the A-Train in 2017, following the failure of one reaction wheel in June 2017 and followed by the unreliable behavior of a second wheel beginning in December 2017. CloudSat is operating successfully on three wheels,

⁷ Although CloudSat and CALIPSO fly in close formation in the C-Train, they are sufficiently far apart that CALIPSO's inability to maneuver would not immediately threaten CloudSat's safety; it would be able to use its own fuel to maneuver to a different altitude.

including formation-flying and collision-avoidance burns. For emergencies and end-of-life de-orbit, burns can be conducted without the wheels, so the loss of an additional reaction wheel—although science-mission ending—would not pose a risk to decommissioning.

CloudSat is proposing to the 2020 Earth Science Senior Review process to extend the mission through 2023 and beyond. CloudSat has ample remaining fuel through 2026 to formation fly with CALIPSO through 2023 and still comply with NASA's 25-year rule for low Earth orbit (defined in this context as below 2000 km, or ~1243 mi).⁸ Significant redundancy on the spacecraft and on the Cloud Profiling Radar (CPR) provides confidence for continued mission operations. CloudSat would continue to operate after CALIPSO is decommissioned in FY23. The CloudSat project reports nearly 3000 peer-reviewed publications using CloudSat data.

Updates on Instruments and Algorithms

There were presentations on the status of the CPR and several CloudSat data products, as well as the status of the CALIPSO Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) and several CALIOP data products. Topics included the CALIOP Level 1 and 2 data

⁸ This rule stipulates that the object will be left in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of the mission but no more than 30 years after launch. This rule is Requirement 56876 of NASA Procedural Requirements 8715.6A.

releases, CALIOP low-laser-energy impacts on calibration and data products, and CALIPSO Imaging Infrared Radiometer (IIR) data products. There were also updates on several innovative data products including the joint CloudSat/Orbiting Carbon Observatory-2 (OCO-2) cloud retrievals, the CloudSat Constant-Sensitivity Data Product, column optical depth retrievals from CALIOP ocean-surface returns, CALIOP measurements of surface-elevation and forest-canopy heights, CALIOP sea-ice melting/freezing onset, sea-ice extent, and surface-type characterization. While the CloudSat CPR is operating nominally, the radar's transmit power is slowly declining, and a switch to the backup High-Power-Amplifier (HPA) may be required in 2021. Presentations on the instruments and algorithms may be downloaded from the meeting website.

Science Highlights

The next several sessions highlighted recent science results resulting from analysis of CloudSat and/or CALIPSO data, combined with A-Train and other satellite data, surface measurements, and/or models. There were presentations on topics related to polar regions, radiation and climate, clouds, aerosols, and storms and precipitation. A sampling of what was presented in each session is provided here. See the full agenda and presentations at the URL listed above for more details.

Polar Regions

Yuekui Yang [NASA's Goddard Space Flight Center (GSFC)] discussed how he used CALIOP, Moderate Resolution Imaging Spectroradiometer (MODIS, on

Aqua), and surface observations from 2009 to 2011 to determine a high-probability pathway for blowing snow in Antarctica from west of Dome Fuji to off-the-coast of George V Land—see **Figure 2**. The results are important to further understand Antarctic surface mass balance and the effects of changes in sea ice amount on both the surface and top of atmosphere (TOA) radiation budgets.

Xia Li [University of Utah] showed how she used data from the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E, on Aqua), CPR, CALIOP, and surface measurements to examine what might be the statistical relationship between wintertime *sea-ice leads* (large cracks in an expanse of sea ice) and low clouds. She found that the occurrence frequency of boundary layer clouds decreases with increasing (open + frozen) lead fraction and that recently frozen leads tend to dissipate low-level clouds. They may be responsible for the observed relationship between ice leads and low clouds.

Radiation and Climate

Brian Soden [University of Miami] used data from CERES (on Aqua), the Atmospheric Infrared Sounder (AIRS) instrument (on Aqua), and CloudSat to investigate how radiative feedbacks modify the climatology of synoptic-scale events. He found that cloud radiative heating can regulate the evolution of tropical cyclones (TCs); developing TCs tend to have greater cloud radiative heating than nondeveloping TCs; cloud radiative interactions accelerate the process of genesis and can be the cause of TC genesis under certain conditions; and radiative coupling also amplifies the responses of many other dynamical events.

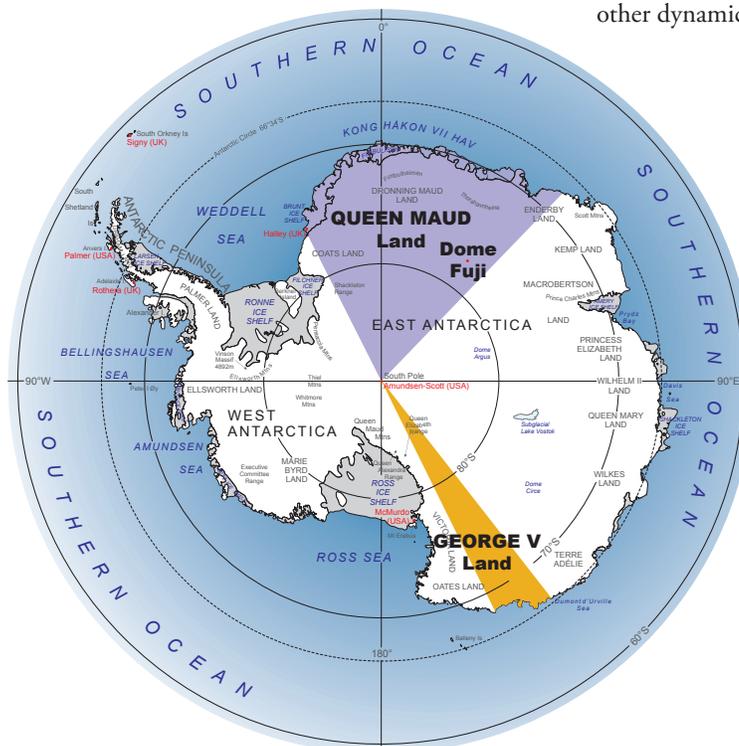


Figure 2. Dome Fuji, also called Dome F or Valkyrie Dome, is an Antarctic base located in the eastern part of Queen Maud Land at 77°30'S 37°30'E. With an elevation of 3,810 m (12,500 ft) above sea level, it is the second-highest summit or ice dome of the East Antarctic ice sheet and represents an ice divide. George V Land is delineated by the tan wedge-shaped segment in the lower right quadrant. **Image credit:** NASA

Seiji Kato [LaRC] used cloud fraction and vertical profile anomalies derived from CALIPSO and CloudSat data to show that cloud fraction decreases with increasing sea surface temperature (SST) over the Eastern Pacific after 2014; cloud-top height increases with SST; negative cloud-fraction anomalies over the Eastern Pacific after 2014 are due to positive SST anomalies and weak positive anomalies or nearly a climatological value of estimated inversion strength (EIS); and anomalies of EIS do not compensate for positive anomalies of SST influencing cloud-fraction anomalies.

Clouds

John Haynes [NASA HQ—*Program Manager for Health and Air Quality Applications*] explored the use of CPR and CALIOP data to improve operational NOAA algorithms. Most cloud information from the GOES-R⁹ Advanced Baseline Imager (ABI) is concentrated near the top of the topmost layer, but multilayer clouds are common and are important for aviation forecasting. Using offline matchups between data from the Visible Infrared Imaging Radiometer Suite (VIIRS)¹⁰ and data from CloudSat/CALIPSO, Haynes and his colleagues developed a method to retrieve the geometric thickness of the topmost cloud layer in any GOES ABI scene given the corresponding cloud water path. Machine learning shows promise as a way to improve low cloud detection, combining ABI and non-ABI data, without requiring inflexible humidity thresholds. They are currently working to expand the algorithm to work for nighttime retrievals, and they are establishing a UNIDATA local data manager feed with the Aviation Weather Center for forecasting evaluation.

Hanii Takahashi [JPL] presented trends in cloud-top heights observed by CloudSat. She reported that no statistically significant trends have been observed to date over the 14-year data record. However, analysis of a 90-year climate model simulation coupled with a CloudSat instrument simulator suggests that if carbon emissions continue on a business-as-usual scenario it is likely that statistically significant upward shifts in cloud heights will be observable in the mid-to-late 2020s as the atmosphere warms. Takahashi stressed the importance of the upward shifts of clouds with warming, shifts of clouds with warming. She explained that these upward shifts act as positive feedback on climate by enhancing the expected warming. She ended by presenting an analysis that demonstrated that monitoring these expected shifts in cloud heights will be possible with detection capabilities less sensitive than that of

CloudSat—well within reach of the emerging class of miniaturized cloud radars.

Jen Kay [University of Colorado] presented the results of research done in collaboration with Johannes Mülmenstädt [University of Leipzig, Germany] and colleagues. This study identified important negative cloud feedbacks that exist through mechanisms that affect cloud lifetime and used CloudSat data specifically to evaluate the fidelity of lifetime processes as reflected in observations of drizzle and light rain occurrences. When changes to the model representation of the production of light rain are introduced to better replicate CloudSat observations, a strong lifetime-related negative feedback resulted. This feedback is large enough and important enough to cast doubt on the notion that the increased climate sensitivity reported in the sixth phase of the Coupled Model Intercomparison Project is a better approximation of the true climate sensitivity than earlier assessments.

Aerosols

Alexander Marshak [GSFC] used MODIS, CALIOP, and VIIRS data to show that cloud fraction and aerosol optical depth (AOD) are positively correlated through most of the globe and for all aerosol types. In many areas, aerosol size distributions shift toward smaller sizes when cloud fraction increases. He noted that cloud contamination does not dominate the near-cloud changes in MODIS aerosol statistics. An analytical model is being developed and tested with CALIPSO to help aerosol retrievals by estimating three-dimensional reflectance enhancements.

Xiaohong Liu [Texas A&M University] described research that used CALIOP, MODIS, and Multiangle Imaging Spectroradiometer (MISR, on Terra) data to determine that aerosol models differ largely in emission (two times), deposition (four times), and lifetimes (two times), but produce quite similar global burdens and dust optical depth (DOD). There are large uncertainties among satellite retrieved DOD and extinction. Models underestimate dust transport from sources, due to faster decay. Models underestimate dust extinction in the lower troposphere while overestimating it in the upper troposphere.

Amber Soja [LaRC] showed results from a study that concluded that CALIOP data can be used to initialize, verify, validate, and improve smoke-plume parameterization in air-quality and chemical-transport models (CTMs). These data provide a spatially and temporally random view of fire-plume data—i.e., one that is not limited to particular fire types or times of day. They can also define the evolution of smoke over a day—which is a completely new result. The satellite data also can be used as model input for many application

⁹ GOES-R stands for Geostationary Operational Environmental Satellite—Series R. This includes GOES-16 (launched in 2016), GOES-17 (launched in 2018), and will include GOES-T (-18) and GOES-U (-19). Note the letter designation switches to a number after launch.

¹⁰ VIIRS flies on the Suomi National Polar-orbiting Partnership mission, as well as on NOAA-20.

processes that define plume injection height for air quality, CTMs, and climate-change feedbacks.

Storms and Precipitation

Mark Smalley [JPL] presented “The Hazards of viewing only the highest clouds in tropical rains.” The analysis merged CloudSat light rainfall estimates with heavy rainfall estimates from the Dual-frequency Precipitation Radar (DPR) on the Global Precipitation Measurement (GPM) mission. The distribution of rainfall is combined in a manner that preserves the occurrence frequency of rainfall as observed by CloudSat while adding the light rain that is missed by the DPR. Smalley also showed that the cloud vertical structure as observed is associated with the entire rainfall spectrum. The results demonstrated that a significant fraction of the rainfall in the tropics falls from shallow clouds and further demonstrates that many of these low clouds are obscured from passive sensors by overlying high clouds. The results call into question the capabilities of precipitation-merging algorithms that use passive infrared observations to temporally interpolate precipitation estimates between higher-quality microwave observations.

Future Missions and Concepts

As described earlier, the 2017 Earth Science Decadal Survey recommended a new Designated Observable mission focused on aerosol, cloud, convection, and precipitation, and their linkages. **Graeme Stephens** [JPL—*CloudSat PI*] and **Dave Winker** [LaRC—*CALIPSO PI*] presented an overview of the ACCP mission study, which was initiated in October 2018 to develop a proposed architecture for the ACCP mission. GSFC is the lead NASA Center, with participation by JPL, LaRC, NASA’s Marshall Space Flight Center, NASA’s Glenn Research Center, and NASA’s Ames Research Center. It also includes numerous U.S.

universities, and four international partners offering contributions: the Japan Aerospace Exploration Agency (JAXA), the French Centre Nationale d’Études Spatiale (CNES), the Canadian Space Agency, and the German Deutsches Zentrum für Luft- und Raumfahrt (DLR). The science objectives of ACCP trace to the need for both active (radar, lidar) and passive (polarimeter, spectrometer, radiometer) instruments.

The study team will present its recommendations to NASA HQ in early 2021. The recommended architectures may reflect a combination of large and small platforms in one or more orbital planes. The first ACCP platform(s) are scheduled to launch in the late 2020s.

Damien Josset [U.S. Naval Research Laboratory (NRL)] explained the “Rainbow Mission” concept¹¹ for a cloud lidar in space with one large lidar and several receivers on CubeSats. The preliminary design review will occur around May 2020 with a plan to test the prototype on the NRL Twin Otter aircraft.

Conclusion

The CALIPSO/CloudSat Annual Science Program Review was deemed very successful. The depth and breadth of science research presented at the Review underscores the always-increasing importance of the climate-data record provided by these two missions. As CALIPSO and CloudSat approach year 15 of operations, we can anticipate even more exciting research results at the next Review sometime in 2021. The CALIPSO and CloudSat Projects express appreciation to all who traveled to take part in person, just as the clouds of COVID-19 were gathering on the horizon. ■

¹¹ To learn more about the “Rainbow” concept, see <https://www.nopp.org/projects/rainbow-a-multistatic-space-lidar-constellation>.

In Memoriam: W. Timothy Liu

The Earth Observer is saddened to report the passing of a valued member of the ocean–atmosphere interaction and climate research community.

W. Timothy Liu [NASA/Jet Propulsion Laboratory (JPL)] passed away on August 14, 2020. After finishing his education, Tim had a long and distinguished career at JPL that dated back to 1979. During that time, he served as the lead of NASA’s Ocean Vector Wind Science Team for a number of years and as project scientist for the NASA Scatterometer (NSCAT) and Quick Scatterometer (QuikSCAT) missions. In addition, he was also a member of the science team of several other NASA missions. Tim won numerous prestigious awards throughout his career. *The Earth Observer* staff extends our condolences to Tim’s family and to his colleagues throughout the scientific community. He will be missed.

More details on Tim’s career accomplishments can be found at <http://science.jpl.nasa.gov/people/Liu>.



Summary of the Thirty-Second and Thirty-Third CERES Science Team Meetings

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Introduction

The thirty-second Clouds and the Earth's Radiant Energy System (CERES)¹ Science Team Meeting (STM) was held October 29-31, 2019, at The Graduate Berkeley in Berkeley, CA—because wildfires made the original site at Lawrence Berkeley National Laboratory (LBNL) inaccessible. The thirty-third meeting, which had been scheduled for April 28-30, 2020, at NASA's Langley Research Center (LaRC) in Hampton, VA, had to be held virtually on those dates due to the shutdowns necessitated by the ongoing 2019 novel coronavirus (COVID-19) pandemic. **Norman Loeb** [LaRC—*CERES Principal Investigator (PI)*] chaired both meetings, the contents of which will be addressed here.

Selected highlights from both meetings are summarized in this article. More information on topics briefly mentioned in the summary from both meetings, contained in their presentations, is available on the recently updated CERES website at <https://ceres.larc.nasa.gov/science/presentations>.

Programmatic and Technical Presentations

Every CERES Science Team meeting traditionally includes a variety of programmatic reports from NASA and/or CERES project managers as well as technical updates on the satellite platforms carrying CERES instruments, and various mission components (e.g., instruments, ground systems, data products). This report includes a summary of highlights of the two *State of CERES* presentations made by the CERES PI at the last two meetings, two programmatic presentations given at the fall meeting, and two given at the spring meeting. The programmatic presentations included in the summary were selected because they report on significant new activities and advances since the Spring 2019 CERES STM.² The other presentations can be viewed at the URL referenced above.

State of CERES

At both the spring and fall meetings, **Norman Loeb** gave a *State of CERES* report thus providing the latest

¹ There are currently six CERES instruments active on four satellites: two on Terra [Flight Model-1 (FM-1) and FM-2]; two on Aqua [FM-3 and -4]; one on the Suomi National Polar-orbiting Partnership (NPP) satellite [FM-5]; and one on the National Oceanic and Atmospheric Administration-20 (NOAA-20) [FM-6].

² See the “Summary of the Thirty-First CERES Science Team Meeting” in the July–August 2019 issue of *The Earth Observer* [Volume 31, Issue 4, pp. 23–26—<https://go.nasa.gov/2WD7IK2>].

updates on recent progress in fulfilling the major objectives of the CERES Science Team. During these presentations, Loeb:

- reviewed the performance and calibration of all CERES instruments—specifically, reporting that there have been no changes in instrument health and calibrations remain consistent;
- provided an overview of the Suomi National Polar-orbiting Partnership (NPP) Edition 2 data products;³
- provided an overview of the National Oceanic and Atmospheric Administration (NOAA)-20 Edition 1 data products, which are about ready for release to the public;
- demonstrated progress on Terra and Aqua Edition 5 data product development;
- provided a status update for the Earth Venture Continuity-1 (EVC-1) mission (see **David Considine** and **Peter Pilewskie**'s presentations discussed on page 24 for more details); and
- discussed data product validation.

In addition, during the spring virtual meeting, Loeb shared highlights from the CERES Terra first light twentieth anniversary event held in February 2020 at LaRC—see *CERES Terra First Light Twentieth Anniversary Celebration* on page 23. He also provided an initial look at changes in clear-sky shortwave (SW) top-of-atmosphere (TOA) flux due to the impacts from many shelter-in-place orders associated with the COVID-19 outbreak. For example, in the East Asian Marginal Seas, a SW TOA flux drop of 4.1 W/m² occurred, compared to the 2003 to 2019 March mean—see **Figure 1**. This anomaly is significant at the 95% confidence interval. The clear-sky SW radiance correlates strongly with aerosol optical depth data from the Moderate Resolution Imaging Spectroradiometer (MODIS).⁴

³ For details, see page 37 of the “Summary of the Thirtieth CERES Science Team Meeting and 2018 Earth Radiation Budget Workshop” in the November–December 2018 issue of *The Earth Observer* [Volume 30, Issue 6, p. 37—<https://go.nasa.gov/2YPR0mg>].

⁴ Like CERES, MODIS instruments fly on NASA's Terra and Aqua platforms.

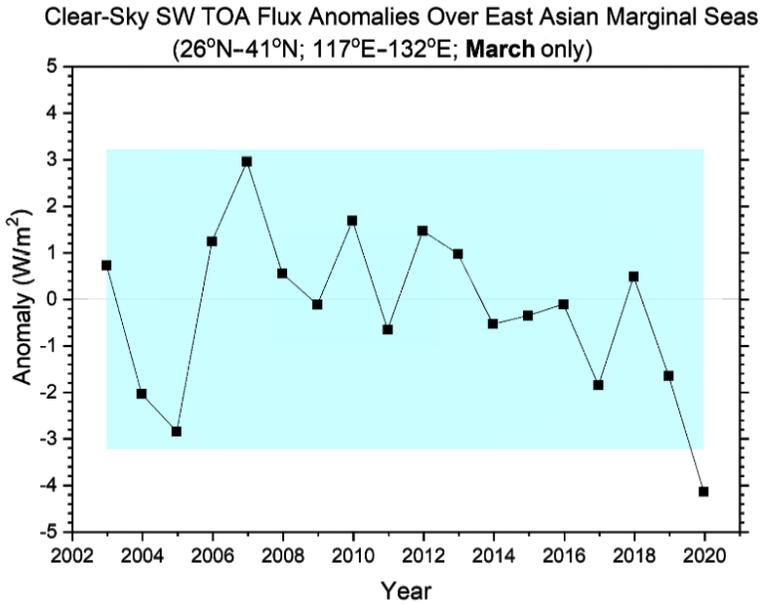


Figure 1. The Aqua Clear-Sky SW TOA Flux anomalies over the East Asian Marginal Seas were obtained by subtracting the mean March flux for the period 2003 through 2019 from the observed values each year in March. The blue area is the 95% confidence interval. The -4.1 W/m^2 March 2020 anomaly is likely attributable to the various Asian nations' stay-at-home orders put in place to slow the spread of COVID-19. **Image credit:** Norman Loeb

Other Programmatic Presentations

During the fall meeting, **Mohan Shankar** [LaRC] discussed the updated calibration corrections and time-varying spectral response function correction to changes in filter absorption at different wavelengths, implemented for the Suomi NPP Flight Model-5 (FM-5) CERES instrument in the Edition 2 products. Likewise, calibration corrections had been incorporated into the NOAA-20 FM-6 instrument in the Edition 1 products by the spring 2020 meeting. Because there was a sharp rise in the FM-6 sensor response—1.5% in SW and 2.5% in total-channel responses—the first three months of data are not suitable for climate trends. Thus, the NOAA-20 climate record begins in May 2018.

Also during the fall meeting, **Bill Smith, Jr.** [LaRC] showed how putting the Visible Infrared Imaging Radiometer Suite (VIIRS) radiances on a consistent radiometric scale produced consistent cloud properties between the VIIRS instruments on Suomi NPP (Edition 2) and NOAA-20 (Edition 1). CERES uses an onboard imager to derive cloud properties needed to determine fluxes.

During the spring meeting, **Moguo Sun** [LaRC/Science Systems and Applications, Inc. (SSAI)] described a new data product, Flux By Cloud Type (FluxByCldTyp), released in June 2020. The product provides daytime CERES fluxes and MODIS-derived cloud properties from the single scanner footprint (SSF) data stratified into forty-two cloud-type bins based on cloud optical depth and effective pressure.

In another spring meeting presentation, **Seiji Kato** [LaRC] presented results using the Energy Balanced and Fill (EBAF) data to show that global all-sky surface albedo has been decreasing at the rate of -0.19 per decade which equates to about 0.36 W/m^2 per decade, in SW surface flux—see **Figure 2**. The mean surface albedo is defined as SW flux reaching the surface divided by the reflected SW from the surface times a 100, i.e., a range of 0 to 100. The decrease is driven by decreasing sea ice cover in the polar regions and less snow over land. The albedo has also been decreasing over the Sahara desert, India, and the Arabian Peninsula, which is not understood yet, although it could be related to trends in the aerosol optical depth.

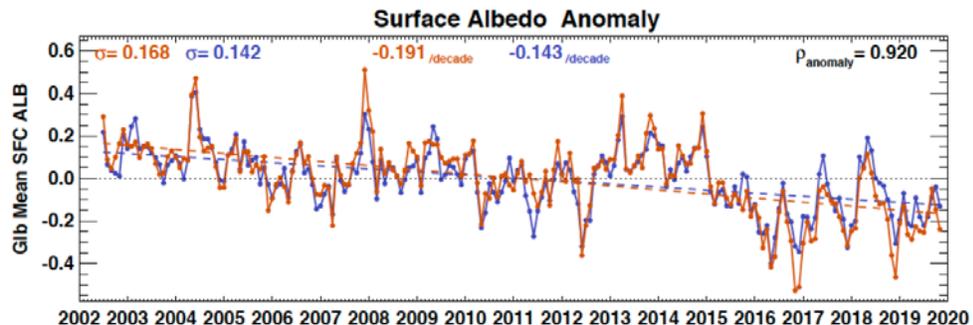


Figure 2. The mean global surface albedo anomaly from July 2002 through November 2019 from the EBAF product. The all-sky surface albedo is decreasing at -0.191 per decade (red) and the clear-sky surface albedo is decreasing at a slightly lower rate of -0.143 per decade (blue). **Image credit:** Seiji Kato

CERES Terra First Light Twentieth Anniversary Celebration

Seventy-five current and past members of the diverse group of instrument engineers, software engineers, scientists, administrative, and budget experts that have worked on the CERES mission gathered on February 27, 2020, at NASA's Langley Research Center (LaRC) to commemorate the twentieth anniversary (which was February 25) of first light for the two Terra CERES instruments and the remarkable data record that has resulted.

Norman Loeb [LaRC—*CERES Principal Investigator (PI)*] covered the history and highlights on the path to this important milestone. The concept that became CERES goes back to the late 1980s when the late **Bruce Barkstrom** [1944–2018], who was the first CERES Instrument PI from 1998 to 2001, wanted to improve on the measurements done by the Earth Radiation Budget Experiment (on which he was also PI) and made a proposal for a group of Earth radiation budget instruments to be included as part of the Earth Observing System (EOS). At the same time, **Bruce Wielicki** [LaRC—*CERES PI from 1989 to 2008 and CERES Science Team Leader*], who was present for the celebration, had proposed interdisciplinary science use of the Earth radiation budget data that the new instruments would provide. Both proposals were selected and given the name Clouds and the Earth's Radiant Energy System, with the acronym CERES, a clever homage to the Roman goddess of agriculture, home, family and stability. At that time, no one was expecting that the instruments, which were designed to operate for 7 years, would still be operating 20 years after launch, enabling the longest-ever Earth radiation budget record from scanning broadband radiometers. As described in this article, the newly selected Libera mission (named



Attendees of the CERES Terra First Light Twentieth Anniversary Celebration on February 27, 2020. Many current and former CERES Science Team members participated in this event. Owing to the COVID-19 pandemic and resulting travel restrictions, this would be the last opportunity for team members to gather in person for a group photo for quite some time. **Photo credit:** LaRC

after the daughter of Ceres) will build on the long heritage of CERES and ensure continuity of the Earth radiation budget time series into the next decade.

Using the data from the six CERES instruments still in orbit—including two on Terra, two on Aqua, one on the Suomi National Polar-orbiting Partnership mission, and one on NOAA-20—the team has pioneered data fusion in generating climate data records: No other satellite team matches CERES in terms of the number of instruments and ancillary datasets used to create data products. In total, 30 instruments on 24 spacecraft have been used so far to produce an accurate and temporally consistent description of the radiation budget. These datasets have provided complete spatial coverage of the Earth—hourly at the top of atmosphere, within the atmosphere, and at the surface.

CERES data products have contributed to a variety of disciplines, including:

- evaluating climate and weather models;
- quantifying how planetary heat uptake changes on monthly-to-decadal timescales;
- constraining climate projections of future warming;
- quantifying aerosol forcing;
- quantifying heat transport in the atmosphere and ocean;

- monitoring changes in polar regions; and
- supporting applied sciences.

Data from CERES also form one of the top three high-priority datasets used for evaluating climate models.

Jim Coakley [Oregon State University], one of the original CERES Science Team members, said, “Among the most significant successes of CERES was a re-examination of Earth’s top of atmosphere and surface energy budgets with a partitioning of the radiative heating in the troposphere. Not only were better estimates of radiative fluxes obtained, but also traceable knowledge of their accuracies and how the fluxes might be improved. Twenty years ago, we would not have believed such knowledge was within reach.”

In a prerecorded video, **David Considine** [NASA Headquarters (HQ)] offered congratulations. He mentioned the impact CERES has made on the science community—as reflected by the value of its observation in the 2017 Earth Science Decadal Survey (referenced in footnote 5) with Libera chosen as the first Earth Venture Continuity mission; he offered kudos to the CERES Science Team for creating and maintaining such an incredible record; and he challenged the Team to press forward toward the goal of establishing a 40-year ERB record.

Updates on Future Earth Radiation Budget Missions

David Considine [NASA Headquarters (HQ)] spoke about the selection of the winning instrument from the EVC-1 solicitation, a low-cost, cost-capped mission that will extend current NASA Earth Radiation Budget climate data records. The program is in response to the recommendation in the 2017 Decadal Survey⁵ to continue the Program of Record for key observations, but to do so more efficiently. The University of Colorado Boulder's Laboratory of Atmospheric and Space Physics (CU-LASP, hereinafter referred to as LASP) instrument, *Libera*, named for the daughter of Ceres in ancient Roman mythology, was selected in February from four submitted proposals. The *Libera* proposal was judged to be the most consistent with the intent of EVC, provides needed measurement continuity, offers the most innovative and capable technology, delivers top-notch science, and was the most cost-effective proposal.

Considine also provided background on two Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP) awards that measure the Earth Radiation Budget. They were DEMonstrating the Emerging Technology for measuring the Earth's Radiation (DEMETER) and Black Array of Broadband Absolute Radiometers–Earth Radiation Imager (BABAR-ERI). **Anum Ashraf** [LaRC] was selected as DEMETER's PI. DEMETER will improve spatial resolution by a factor of 10 over that of CERES while significantly reducing the size of the instrument. **Odele Coddington** [LASP] was selected as BABAR-ERI's PI. Coddington and his team will develop a closed-loop, absolute, electrical substitution radiometer that eliminates the need for an onboard calibration source.

Peter Pilewskie [LASP] has been designated PI for *Libera*. He gave a presentation describing the instrument and how it will provide measurements for the same three channels as CERES FM-6, with an additional split-SW (0.7–5.0 μm) channel. The field-of-view size and scanning modes for *Libera* will be the same as those for CERES, and it will employ the same calibration methods as CERES. *Libera* will use electrical substitution radiometers using vertically aligned carbon nanotube (VACNT) detectors, which are being used on the Total Spectral Solar Irradiance Sensor–1 (TSIS-1), and will be one of the instruments onboard Joint Polar Satellite System-3 (JPSS-3), slated for launch in 2027. The *Libera* team will be responsible for providing the calibrated radiances to the Earth Radiation Budget Science (ERBS) Project that will then produce the Level 2 and 3 CERES products,

⁵ The 2017 Earth Science Decadal Survey, “Thriving on a Changing Planet: A Decadal Strategy for Earth Observation from Space,” can be viewed at and downloaded from <https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth>.

such as SSF, SSF one-degree (SSF1deg), and synoptic one-degree (SYN1deg), using the new instrument's measurements.

Invited Science Presentations

As primary users of CERES radiation and flux data, the modeling community employs these data to validate and analyze climate general circulation models. Four modeling representatives gave invited presentations at the fall 2019 meeting and two others spoke at the spring 2020 meeting.

Fall Meeting Presentations

William Boos [LBNL] showed how he used CERES atmospheric energy budget data to track Global Precipitation Climatology Project (GPCP)⁶ tropical rainfall variations. The net radiance input drives global atmospheric circulation, which in turn sets up the precipitation distribution. Earth has a large seasonal cycle of rainfall, mostly associated with monsoons. This is especially true over the Northern Indian Ocean, where clouds are colder and more extensive than anywhere else on the planet. The strong tropical cloud radiative effect (CRE) aligns with these precipitation increases. Boos also related the large precipitation bias that Coupled Model Intercomparison Project 6 (CMIP6)⁷ models have in tropical rainfall to a large positive bias in net energy input over the Southern Ocean. The CERES radiative flux estimates can provide an important observational constraint on the net energy input in such models.

William Collins [LBNL] guided the group through using machine learning in detecting climate extremes, including tropical cyclones (TC), atmospheric rivers (AR), and weather fronts. These weather patterns are searched for in Community Atmosphere Model Version 5 (CAM5)⁸ quarter-degree simulation data. The training data are developed using the Toolkit for Extreme Climate Analysis (TECA), developed at LBNL, which provides a framework to produce a training dataset by managing input data, implementing algorithms to identify specified features, and assigning labels to them. Processing the training dataset requires significant resources, as a result of which it stresses all

⁶ GPCP is a NOAA dataset that provides monthly, five-day, and daily precipitation analyses from surface and satellite measurements dating back to 1979 for monthly data and 1997 for daily data.

⁷ CMIP is a standard experimental framework for studying the output of coupled atmosphere–ocean general circulation models, allowing assessment of model strengths and weakness and contributing to the development of future models. There have been six CMIP phases to date, with CMIP-5 and CMIP-6 mentioned in this article. Learn more at <https://www.wcrp-climate.org/wgcm-cmip>.

⁸ CAM5 is the latest in a series of atmospheric models developed by the National Center for Atmospheric Research (NCAR).

aspects of Summit, the most recent and most powerful Oak Ridge Leadership Computing Facility (OLCF) Exascale Hardware. He also identified ClimateNet as a critical activity that works to label climate features in model, satellite, and observational datasets, which could support this work.

Daniel Feldman [LBNL] described his work, looking at temporal dimensions of SW CRE from the CERES hourly SYN1deg product. One source of bias in CERES SW CRE is in cloud diurnal cycles, which is problematic, since the observations are made at fixed local solar hours. The CERES SYN1deg product incorporates cloud properties derived from geostationary imagery to provide diurnal information. Narrow-band imagery from the Earth Polychromatic Imaging Camera (EPIC) and broadband Earth-as-a-pixel radiance from the National Institute of Standards and Technology Advanced Radiometer (NISTAR) are used for this analysis.⁹ These instruments provide continuous observation of the sunlit portion of Earth. An analysis of the mode of variability in Reflected Shortwave Radiance (RSR) from two years of observation reveals similar variability in frequency between all three instruments; no discernible bias was present between the instruments. Comparing CMIP5 model fluxes with the observations shows systematic biases across models in mean diurnal cycle.

David Romps [University of California Berkeley (UCB)] explained stereo photogrammetry of clouds, noting that multiple cameras would be able to measure the width and vertical growth of cumulus clouds. Initially, two cameras were installed at the Department of Energy's Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Central Facility. The ARM data are available in the Point Cloud of Cloud Points (PCCP) product, which provides a collection of three-dimensional positions of cloud features. It has since been expanded to three pairs of cameras to provide information on all sides of a cloud. A second product has been developed called Clouds Optically Gridded by Stereo (COGS); it identifies where in the viewed three-dimensional atmosphere the clouds are located. The resulting vertical velocities have shown that accelerations in these plumes are much smaller than their buoyancy, so cloud thermals can be described colloquially as “being sticky” or “rising viscously.” A large-eddy simulation showed that the measured constant rise of the cloud requires that buoyancy and drag be balanced, consistent with the observations.

Spring Meeting Presentations

Stephan Fueglistaler [Princeton University (PU)] provided arguments that recent global warming has

⁹ Both these instruments fly on the Deep Space Climate Observatory (DSCOVER), launched in 2015.

been peculiar since the late 1970s due to a drastic change in the relationship between average sea surface temperature (SST) and SW CRE. From 1871 through 1979 an increase in SST led to higher SW CRE, but after 1979 SW CRE decreased with increasing SST. When the difference between global SST and the SST in the region of convection that has the warmest temperature (in this case, the Pacific Ocean, referred to as SST#) is included with the global SST in a multiregression analysis, the model relationship with SW CRE is better explained. Higher tropospheric temperature leads to stronger boundary layer capping and consequently more clouds and a negative SW CRE. However, the data show that SST# has a significant upward trend in the late 1970s, that is not seen in the global SST. Since most satellite observations were acquired after 1979, the observation does not capture the longer SW CRE trends seen in models. This underestimates the climate sensitivity calculated during the latter observation period.

George Tselioudis [NASA's Goddard Institute for Space Study (GISS)] examined how shifts in main observed features of the atmospheric zonal mean circulation affect various components of the CRE. He explained how a poleward shift from the Equator in Hadley Cell convection is followed by a similar movement in high clouds in almost all ocean basins and seasons; a poleward shift in the jet stream has a corresponding shift in high clouds only in the North Atlantic during Northern Hemisphere winter months. A shift in either the North Atlantic Hadley Cell or jet stream results in total cloud decrease and SW warming in the lower midlatitude surface. However, the poleward shift in the Hadley Cell in the Southern Ocean does not change total cloud amounts and produces weak SW cooling in the lower midlatitude surface. There is also a weaker vertical velocity response in the Southern Ocean than in the Northern Atlantic. Climate models are used to determine how these circulations change. The lower midlatitude SW CRE warming in CMIP5 is more dependent on the Hadley Cell circulation position, but this dependence is not seen in CMIP6. This lack of realistic positions of the Hadley Cell in CMIP6 prevents the equilibrium climate sensitivity (ECS) from being correctly constrained and thus results in higher ECS.

Contributed Science Presentations

Combined, between the fall and spring meetings there were 35 contributed science presentations. They provided information on subjects such as:

- input or validation data sources used by CERES;
- status of algorithm development, including understanding conditions where current algorithms perform poorly;

- validation efforts from field campaigns and independent measurements;
- energy budget in the Arctic; and
- new instruments, including Athena and Far-Infrared Outgoing Radiation Understanding and Monitoring (FORUM).

Owing to space limitations, only the presentation related to the new Athena and FORUM instruments are highlighted here.

Kory Priestley [LaRC] presented an overview of Athena, a sensorcraft for measuring Earth's radiation budget. A partnership between NASA, NOAA, and the U.S. Air Force, Athena will consist of an optical module, a single CERES total channel sensor, a calibration module, the CERES internal blackbody, and a new sensor electronics assembly. Athena's modules will be incorporated on a NovaWurks Hyper-Integrated Satlet (HISat).¹⁰ It will be a secondary, small satellite payload on JPSS-2 (scheduled for launch in 2022) by way of an Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA). Athena will weigh only 5 kg (11 lbs) and be a 15-cm (5.9-in) cube. It will be able to perform fixed-azimuth: cross-track or along-track; rotating azimuth: bi-axial; and staring scanning matching the CERES instrument movements. This effort is to demonstrate the configurability of HISat maneuverability of the sensorcraft to provide spatially matched observations with other satellites, and fine pointing control.

Marty Mlynczak [LaRC] described FORUM, which is the European Space Agency's (ESA) ninth Explorer Mission. The instrument will measure the previously unobserved far-infrared (FIR) wavelengths longer than

15.5 μm using a Fourier Transform spectrometer. It will build on 20 years of ground, aircraft, and balloon-borne instruments that demonstrated technologies for measuring the FIR. For observed range of Earth's surface temperature, the peak energetic emission is in the FIR. The FIR represents around half of Earth's outgoing longwave (LW) radiance (OLR); dominant contribution to clear-sky atmospheric radiative cooling, a key driver of atmospheric dynamics; and a large contributor to atmospheric heat trapping, the so-called greenhouse effect.

Conclusion

This is an exciting time, looking to the future of Earth radiation measurements with selection of Libera as the successor to the CERES instrument. Three other instruments will demonstrate new technologies to improve Earth radiation measurement resolution and accuracy at a lower cost. A new data product, FluxByCldTyp, that provides SW and LW flux for specific cloud types, has been released. Improved calibrations on the Suomi NPP Edition 2 and NOAA-20 Edition 1 suite of products are now being produced. Truly diurnal measurements of SW fluxes have shown that CERES algorithms have successfully captured that cycle.

Comparison between CERES observations and general circulation models have identified a large positive bias in net energy input over the Southern Ocean, leading to a large precipitation bias and emphasis on the importance of realistic placement of the Hadley Cells in obtaining better estimates of ECS. Observational studies of SST have shown that recent variations in the range of SSTs can impact SW CRE leading to misrepresentation of the ECS obtained from the shorter-period satellite observations.

The next CERES STM will be held—again, virtually—September 15-18, 2020, hosted from LaRC. ■

¹⁰ HISats are a type of CubeSat that incorporate all the technology of a regular satellite into a mass-produced 20 x 20 x 10 cm (~8 x 8 x 4 in) module or cell.

Could COVID-19 Have Seasons? Searching for Signals in Earth Data

Dating at least as far back as Ancient Greece, humans have sought to understand the seasonal nature of illnesses. Modern technology—most notably Earth-observing satellites—has revolutionized our ability to continuously monitor environmental conditions on a global scale in ways ancient observers could scarcely have imagined.

However, even though more information than ever is available for analysis, explaining why some diseases have seasonal cycles and others do not remains a challenge, as does predicting the precise timing of those cycles in order to mitigate potential harmful impacts on society. In 2020 the impetus to address this issue has increased as a result of the global pandemic of novel coronavirus (SARS-CoV-2) and the disease it causes (COVID-19).

As described in the News story on page 28 of this issue, NASA and its international partners are working together to collect information to help them examine potential relationships between the spread of COVID-19 and seasonal shifts in humidity, temperature, rainfall, and other environmental variables. They hope their work will clarify the role that weather and climate might play in influencing the spread of the virus.

As part of NASA's ongoing effort to report the latest on its efforts to study COVID-19, the *Earth Observatory* website has published an excellent feature article that explains how NASA and its partners are working to understand potential seasonal cycles in COVID-19. Author **Adam Voiland** first examines the subject of seasonal cycles in respiratory viruses generally, and then describes specific research toward “finding patterns in a flood of data” that help scientists understand the impact of various environmental factors that influence the spread of COVID-19. As Voiland's article explains, the task is not trivial, as the researchers must “disentangle the role of seasonal change from the other factors influencing [the spread of] SARS-CoV-2, such as travel and economic restrictions or wearing masks.”

We here at *The Earth Observer* encourage you to read the full article posted at <https://earthobservatory.nasa.gov/features/covid-seasonality>.



Scientists hope to understand how much environmental conditions influence the spread of COVID-19 compared to other factors like mask wearing or quarantines. **Photo credit:** Zydeasikal/pexels.com

NASA, Partner Space Agencies Amass Global View of COVID-19 Impacts

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While this material contains essentially the same content as the original release, it has been rearranged and wordsmithed for the context of *The Earth Observer*.

In response to the global coronavirus (COVID-19) pandemic, NASA, the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA) have joined forces to use the collective scientific power of their Earth-observing satellite data to document planetwide changes in the environment and human society. The wealth of these agencies' collective information now is available at the touch of a finger.

In an unprecedented collaboration, the three space agencies have created the joint COVID-19 Earth Observation Dashboard (<https://eodashboard.org>), which integrates multiple satellite data records with analytical tools to allow user-friendly tracking of changes in air and water quality, climate change, economic activity, and agriculture. Leaders from each agency discuss the collaboration in a video (see **Figure 1**) available at <https://svs.gsfc.nasa.gov/13650>.

This tri-agency data resource gives the public and policymakers a unique tool to probe the short-term and long-term impacts of pandemic-related restrictions implemented around the world—see **Figure 2** on page 29. The dashboard will continue to grow with new observations added over the coming months as the global economy gradually reopens.

“Together NASA, ESA, and JAXA represent a great human asset: advanced Earth-observing instruments in space that are used every day to benefit society and advance knowledge about our home planet,” said

Thomas Zurbuchen [NASA Headquarters—*Associate Administrator of the Science Mission Directorate*]. “When we began to see from space how changing patterns of human activity caused by the pandemic were having a visible impact on the planet, we knew that if we combined resources, we could bring a powerful new analytical tool to bear on this fast-moving crisis.”

In April, the three agencies formed a task force to take on the challenge. The group identified the most relevant satellite data streams and adapted existing computing infrastructure to share data from across the agencies and produce relevant indicators. The dashboard presents users with seamless access to data indicating changes in air and water quality, economic and agricultural activity on a global scale, and in select areas of interest.

Air quality changes around the world were among the first noticeable impacts of pandemic-related stay-at-home orders and reductions in industrial activity that emerged from satellite observations. Nitrogen dioxide (NO₂), which is an air pollutant that is primarily the result of burning fossil fuels for transportation and electricity generation, shows up clearly in satellite data. NO₂ has a lifetime of a few hours and is a precursor of ground-level ozone, which makes it a useful indicator of short-term air quality changes. The dashboard brings together current NO₂ data from two NASA and ESA satellites, along with historical data for comparison. In addition to the global view of NO₂, targeted regional areas include Los Angeles, CA; Tokyo, Japan; Beijing, China; Paris, France; and Madrid, Spain.



Figure 1. In this video, **Thomas Zurbuchen** discusses the COVID-19 Earth Observation Dashboard, which harnesses the collective power of space-based observations from NASA, ESA, and JAXA to observe global changes around the world. **Video credit:** NASA's Goddard Space Flight Center



Figure 2. COVID-19 led to changes in human activities around the globe. Some bodies of water have run clearer, emissions of pollutants have declined, and transportation and shipment of goods have decreased. We can see some of these changes from space. NASA, ESA, and JAXA are making satellite data available on the new COVID-19 Earth Observation Dashboard, shown above. To watch a tutorial video on how to navigate the dashboard, visit <https://go.nasa.gov/2CUWKmW>. **Image credit:** NASA/ESA/JAXA

Changes in another critical component of our atmosphere, carbon dioxide (CO₂), are highlighted in the dashboard to probe how global and local reactions to the pandemic have changed concentrations of this climate-warming greenhouse gas. Because of the high background concentration of CO₂ in the atmosphere and its long atmospheric lifetime of more than 100 years, short-term changes in atmospheric CO₂ resulting from changes in anthropogenic emissions are very small relative to expected variations in abundances from the natural carbon cycle.

A recent study in the journal *Nature* estimated that a three-month economic slowdown such as the world has just experienced would temporarily reduce the expected increase in CO₂ concentrations from emissions into the atmosphere by a fraction of a percent. The dashboard presents data from a NASA satellite to look for global-scale, long-term changes in CO₂. Carbon dioxide observations from a JAXA satellite zoom in on changes in select urban areas such as New York, NY, San Francisco, CA, Tokyo, and Delhi, India. Analyses from both NASA and JAXA datasets are consistent with the estimates of emission reductions in the *Nature* study.

Recent water quality changes have been reported in a few locations that typically have intense human activities, such as industry and tourism, which have

decreased during the pandemic. The dashboard presents targeted satellite observations from all three agencies of total suspended matter and chlorophyll concentrations in select coastal areas, harbors, and semi-enclosed bays to assess what has produced these changes in water quality, how widespread they may be, and how long they last. Long Island Sound, the North Adriatic Sea, and Tokyo Bay are among the areas examined.

Widespread declines in global economic activity are a well-known impact of the pandemic. Observations from space over time of shipping activity in ports, cars parked at shopping centers, and nighttime lights in urban areas can be used as indicators of how specific sectors of the economy have been affected. Satellite data from each agency and commercial data purchased by NASA and ESA are presented in the dashboard to quantify these changes in: Los Angeles; the Port of Dunkirk, France; Ghent, Belgium; Beijing, China; and other locations.

The dashboard will also present tri-agency satellite data looking for signs of changes in agricultural production around the world, such as harvesting and planting due to disruptions in the food supply chain or the availability of labor. Understanding the extent of any such changes would be important in maintaining global and local markets and food security as the world recovers from the pandemic. ■

Keeping a Steady Eye on Sea Level Change from Space

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While this material contains essentially the same content as the original release, it has been rearranged and wordsmithed for the context of *The Earth Observer*.

The Copernicus Sentinel-6/Jason-Continuity of Service (Jason-CS) satellite mission will add to a long-term sea level dataset that's become the gold standard for climate studies from orbit.

Over the course of nearly three decades, an uninterrupted series of satellites has circled our planet, diligently measuring sea levels—see **Figure 1**. The continuous record of ocean height that they've built has helped researchers reveal the inner workings of weather phenomena like El Niño and forecast how much the ocean could encroach on coastlines around the world. Now, engineers and scientists are preparing two identical satellites to add to this legacy, extending the dataset another decade.

Both spacecraft are a part of the Sentinel-6/Jason-CS mission, a U.S.-European collaboration¹ that aims to make some of the most accurate measurements of sea levels around the world. The first satellite to launch,

¹ Copernicus Sentinel-6/Jason-CS is being jointly developed by the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), NASA, and the National Oceanic and Atmospheric Administration (NOAA), with funding support from the European Commission and support from France's Centre National d'Études Spatiales (CNES).

Sentinel-6 Michael Freilich,² will lift off in November. Its twin, Sentinel-6B, will launch in 2025. Both will assess sea levels by sending electromagnetic signals down to the ocean and measuring how long it takes for them to return to the spacecraft.

"This mission will continue the invaluable work of accurately measuring sea surface height," said **Karen St. Germain** [NASA Headquarters—*Director of the Earth Science Division*]. "These measurements enable us to understand and predict sea level changes that will affect people living in coastal regions around the world."

The satellite will build on efforts that began in 1992 with the launch of the TOPEX/Poseidon mission and that have continued with three more missions over the years: Jason-1, the Ocean Surface Topography Mission (OSTM)/Jason-2 (Jason-2 hereinafter), and Jason-3. Sentinel-6/Jason-CS aims to extend the nearly 30-year sea level dataset that these previous missions built by another 10 years.

² The first Sentinel-6/Jason-CS satellite was originally called Sentinel-6A. On January 28, 2020, the mission name was changed to honor Michael Freilich, the former director of NASA's Earth Science Division, who passed away August 5 (see "The Editor's Corner" for details). Freilich played a significant role in the development of the mission.

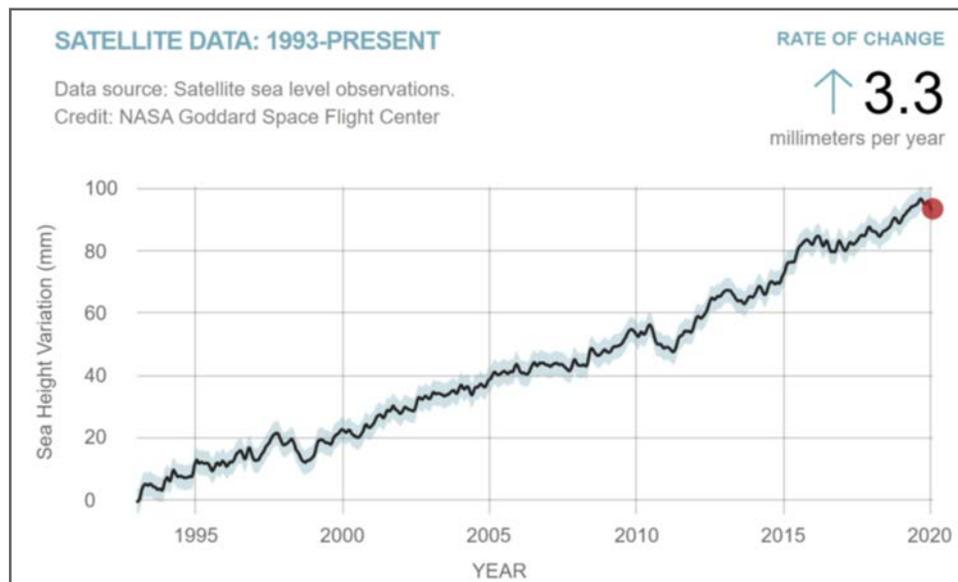


Figure 1. This chart shows the rise in global average sea level from January 1993 to January 2020. The measurement is made using data collected by the Sentinel-6/Jason-CS mission's predecessors, the TOPEX/Poseidon, Jason-1, OSTM/Jason-2, and Jason-3 satellite missions. **Image credit:** NASA's Goddard Space Flight Center

Measuring the height of the ocean gives scientists a real-time indication of how Earth's climate is changing, said **Josh Willis** [NASA/Jet Propulsion Laboratory (JPL)—*Sentinel-6/Jason-CS Project Scientist*]. The ocean absorbs about 90% of the excess heat from the planet's warming climate. Seawater expands as it heats up, resulting in about a third of the modern-day global average sea level rise. Melting ice from land-based sources like glaciers and ice sheets accounts for the rest.

To understand how rising seas will affect humanity, researchers need to know how fast this is happening, said Willis. "Satellites are the most important tool to tell us this rate," he explained. "They're kind of a bellwether for this creeping global warming impact that's going to inundate coastlines around the world and affect hundreds of millions of people."

Currently, sea levels rise an average of 0.13 in (3.3 mm) per year, more than twice the rate at the start of the twentieth century. "By 2050, we'll have a different coastline than we do today," said Willis.

"As more and more people move to coastal regions, and coastal megacities continue to develop, the impact of sea level change will be more profound on those societies," said **Craig Donlon** [European Space Agency (ESA)—*Sentinel-6 Project Scientist*].

Setting the Standard

The information that Sentinel-6 Michael Freilich gathers will join a dataset that's become the gold standard for climate studies from space. This is because the chain of overlapping satellites that started with TOPEX/Poseidon has continuously measured ocean heights since the early 1990s. That continuity is key to this dataset's success.

Some of the long-term datasets climate scientists rely on, like ocean temperature or the height of tides, have gaps or major changes in how data were collected (like before and after satellite records began) that make understanding the long-term climate signal challenging. Researchers must account for these variations to ensure that their results are truly representative of the phenomena they're looking at.

The satellites that followed TOPEX/Poseidon (1992–2006)—Jason-1 (2001–2013), Jason-2 (2008–2019), and Jason-3 (2016–present)—flew in the same orbit as one another, each launching before the older one was decommissioned. When Sentinel-6 Michael Freilich lifts off later this year, it will orbit Earth 30 seconds

behind the Jason-3 satellite, which launched in 2016. Scientists will then spend a year cross-calibrating the data collected by the two satellites to ensure the continuity of measurements from one mission to the next. Engineers and scientists will do the same cross-calibration with Sentinel-6 Michael Freilich's twin in five years as its predecessor's mission winds down.

Without these satellites and the data they've collected, researchers would have a much less precise understanding of the rate of sea level rise, as well as of phenomena like El Niño. This is a weather pattern triggered by a huge shift in the winds that normally blow from east to west across the equatorial Pacific Ocean. An El Niño can shift ocean currents and global weather patterns, bringing torrential rain to the Southwestern U.S. and triggering droughts in Asia and Australia. Its counterpart, La Niña, can have the opposite effect.

One of the discoveries to come out of this sea level dataset is the far-reaching effects that El Niño and La Niña can have on the world. "In 2010, there was a massive La Niña and it essentially flooded huge parts of Australia and Southeast Asia. It rained so much on land, it dropped global sea levels by 1 cm (0.4 in)," said Willis. "We had no idea it could have such a massive impact on global sea level."

The global view that the Sentinel-6 Michael Freilich satellite will provide, together with sea level data from models and observing stations, will provide invaluable information for governments and local authorities tasked with planning for things like sea level rise and storms, said Donlon.

More About the Mission

NASA's contributions to the Sentinel-6/Jason-CS mission are three science instruments for each of the two Sentinel-6 satellites: the Advanced Microwave Radiometer, the Global Navigation Satellite System – Radio Occultation, and the Laser Reflector Array. NASA is also contributing launch services for those satellites, ground systems supporting operation of the JPL-developed science instruments, the science data processors for two of these instruments, and support for the international Ocean Surface Topography Science Team.

Learn more about Sentinel-6/Jason-CS at <https://sealevel.jpl.nasa.gov/missions/jasoncs>. ■

NASA Snow Campaign Wraps 2020 Survey

Jessica Merzdorf, NASA's Goddard Space Flight Center, jessica.v.merzdorf@nasa.gov

EDITOR'S NOTE: This article is taken from *nasa.gov*. While this material contains essentially the same content as the original release, it has been rearranged and wordsmithed for the context of *The Earth Observer*.

As spring and summer temperatures return to the Northern Hemisphere, winter's snow is melting, releasing precious fresh water into Earth's streams, rivers, and ocean. This annual change provides liquid water for drinking, agriculture, and hydropower for more than one billion people around the world. In the future, NASA plans to use a satellite mission to measure how much water the world's winter snowpack contains, and to do that, they need to know what combination of instruments and techniques will efficiently measure this information from space.

NASA's SnowEx¹ campaign is a multiyear effort using a variety of techniques to study snow characteristics, and the team completed their second field campaign in March 2020. SnowEx is learning valuable information about how snow properties change by terrain and over time, and they are also investigating the tools, datasets, and techniques NASA will need to sample snow from space.

"This winter's SnowEx campaign collected valuable data for assessing multiple snow remote sensing techniques. It would not have been possible without the hard work and support of all the participants and partners who helped," said **Carrie Vuyovich** [NASA's Goddard Space Flight Center (GSFC)—*SnowEx 2020 Deputy Project Scientist and Lead Scientist for NASA's Terrestrial Hydrology Snow Program*].

Coming Together to Measure Snow Water

Snow water equivalent (SWE) is how much liquid water is in a volume of snow once it melts, and is deduced from depth and density.

"Depths are simple to measure, yet depths often vary greatly from one place to another and that requires

¹ For more information on SnowEx, visit <https://snow.nasa.gov/campaigns/snowex/about>.

a lot of measurements in different places to get a good estimate," said researcher **Chris Hiemstra** [U.S. Army Corps of Engineers' Cold Regions Research and Engineering Laboratory (CRREL), Fairbanks, AK]. "Density is more challenging because it changes with snow age and local conditions. As an example, fresh cold snowfall is light and airy, with only 5–10% water in flakes you can move with a light breath. In warmer snowpack conditions on the ground, cloud-borne snowflakes fuse and change to larger bonded round grains of higher density. With wind, snow is blown, broken, and packed into drifts, but even then, it is only 40–50% water. Variability in depths and densities makes SWE challenging to map."

Wet snow falling at temperatures around freezing (0 °C or 32 °F) typically has a density of about 8–10 in (~20–25 cm) of snow equaling 1 in (~2.5 cm) of SWE. In other words, it would take about 8–10 in (~20–25 cm) of wet snow at freezing temperatures to get 1 in (~2.5 cm) of melted water. In contrast, snow that falls at colder temperatures, around -4 °C (25 °F), is far less dense: To get 1 in (~2.5 cm) of melted water from snow in these conditions, you might need up to 20 in (~50 cm) of it.

Current satellite missions easily measure how much of the land is covered by snow. But no single satellite currently in orbit contains an instrument or collection of instruments designed to measure SWE and/or the snow characteristics that may be used to calculate it.

For SnowEx 2020's *intensive operating period*, a grueling three weeks of data collection at one site, scientists from around the world traveled to Grand Mesa, CO. It is the world's largest mesa, or flat-topped mountain, and at 11,000 ft (3350 m) above sea level, winters are long and snow can be deep—see **Photo 1**. Its high flat surface and variety of land cover—which ranges from



Photo 1. Grand Mesa, CO, the world's largest mesa, or flat-topped mountain. With terrain ranging from open snow to thick forest, the mesa was a perfect place for the SnowEx 2020 team to test their instruments. **Photo and text credit:** NASA/Jessica Merzdorf

wide-open meadows to dense forests—make it perfect for testing instruments across different conditions.

Through biting cold, dazzling sunshine, heavy snowfall, and high winds, the ground-based team dug, sampled, and refilled more than 150 *snow pits*—car-sized holes in the snow that extend all the way to the ground—allowing them to take measurements of the pit walls and see how snow characteristics vary from top to bottom. Other team members used probes to measure nearly 38,000 snow depths during the three weeks while skiing or snowshoeing in an area the size of a football field around the pits.

“We can see, and even hear, how the snow’s characteristics change from top to bottom,” said Hiemstra. “The newest snow at the top is fluffy and quiet. Below that, the wind has packed it into dense layers that scrape on the shovel. The snow toward the bottom is loose and has sharp pointed edges. When you dig into it, icy points snap and ring as they fall against the shovel.”

The pit crews also measured snow water content, temperature, reflectance, and particle size. Researchers used hand-held instruments to measure snow hardness, microstructure, and depth around the pits. “One challenge with these point observations is the comparison with airborne and spaceborne observations, which have footprints on the order of tens to thousands of meters,” said **Hans–Peter Marshall** [Boise State University/CRREL—*SnowEx 2020 Project Scientist*].

In order to understand the variability in snow properties within these larger remote sensing footprints, the team drove snowmobiles in precise *Hiemstra spirals*—see **Photo 2**—to collect active and passive radar measurements of snow layers, depth, and water content, with more continuous sampling.

“When you look at the data mapped out across the mesa it’s amazing how much area we covered. There are interesting spatial patterns in the snow depth data, where the deep snow forms right along the edges of forested areas,” said Vuyovich. “There is shallower snow depth among the trees and it is average out in the open. This snow depth heterogeneity is mostly due to wind redistribution and really demonstrates why we need so

many observations to validate the remote sensing observations and test our models.”

While the ground teams worked in the snow, airborne teams flew precision flight lines overhead (see **Photo 3** on page 35) carrying instrument combinations that made similar measurements: Radar and lidar for snow depth, microwave radar and radiometers for SWE, optical cameras to photograph the surface, infrared radiometers to measure surface temperature, and hyperspectral imagers to document snow cover and composition. Of the seven instruments that flew on aircraft, two came from NASA: The Snow Water Equivalent Synthetic Aperture Radar and Radiometer (SWESARR) came from GSFC, and the Uninhabited Aerial Vehicle Synthetic Aperture Radar, (UAVSAR) came from NASA/Jet Propulsion Laboratory.

The teams also took advantage of overpasses by several satellites—including NASA’s Ice, Cloud, and land Elevation Satellite–2 (ICESat-2) and Terra missions, and the European Space Agency (ESA) Sentinel-1 mission—to collect additional data to compare. Back on the ground, Vuyovich and her team ran a range of computer models to compare with gathered data later, and see how they compared and might be combined for future analyses.

“The period at Grand Mesa went so well,” said Marshall. “The entire 44-person field crew worked incredibly hard, and in particular, many of the younger students really stepped up. I’m excited about our up-and-coming generation of snow scientists—they will do great things.”

According to Marshall, coordinating both new and mature instruments across a variety of conditions and locations was challenging. “For a seasonal snow airborne campaign, SnowEx 2020 is unique in that we successfully flew so many instruments over the same location, coordinated with extensive field observations,” he said. “Using those datasets together is going to be really exciting. It will take us a long way toward a better understanding of how to develop a global SWE product that combines data from multiple satellites, field data, and modeling.”

continued on page 35



Photo 2. SnowEx 2020 project scientist **Hans–Peter Marshall** drives his snowmobile in a precise spiral called a *Hiemstra spiral*, taking radar measurements of snow layers, depth, and water content. **Photo and text credit:** NASA/Jessica Merzdorf

Early Detection of Algae Blooms by Satellite Yields Healthcare Savings

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While this material contains essentially the same content as the original release, it has been rearranged and wordsmithed for the context of *The Earth Observer*.

The use of NASA satellite data by environmental managers to help them track harmful algal bloom outbreaks along lakefronts and coasts can result in earlier detections that yield significant savings on healthcare, lost work hours, and other economic costs.

A NASA-funded case study published last month in the journal *GeoHealth* reviewed a 2017 algal bloom in Utah Lake, near Provo, UT. It showed that satellite data help lead to earlier warnings of hazardous algae than other detection approaches, and in this case, the earlier notice resulted in approximately \$370,000 in savings.

“Using satellite data to detect this harmful algal bloom potentially saved hundreds of thousands of dollars in social costs by preventing hundreds of cases of cyanobacteria-induced illness,” said study coauthor **Molly Robertson** [Resources for the Future (RFF)]. The analysis is the work of the Consortium for the Valuation of Applications Benefits Linked to Earth Science (VALUABLES), which is a collaboration between NASA and RFF that focuses on advancing innovative uses of existing techniques and developing new techniques for valuing the information provided by Earth-observing satellites.

Some toxin-producing algae can be harmful to human health when the algae are present in high numbers. As can be seen in the left image in the **Figure** below, algal blooms often change the color of bodies of water, making a bloom detectable by Earth-observing satellites.



A researcher takes water samples from Utah Lake. **Photo credit:** NASA/Utah Department of Environmental Quality

For their analysis, the authors used data from the European Space Agency's Copernicus Sentinel-3 satellite as provided by the Cyanobacteria Assessment Network (CyAN). This is a multi-agency project led by the Environmental Protection Agency (EPA) and includes NASA, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS) as partners. CyAN is developing an early warning indicator system to detect algal blooms in U.S. freshwater systems. Also incorporated into CyAN are data from the Landsat series of satellites.

The study's authors compared two possible scenarios in reviewing data from the June 2017 harmful algal bloom in Utah Lake. They concluded that Earth-observing satellite data of the lake showed color changes, and thus the presence of algae, and that this information prompted the Utah Department of Environmental

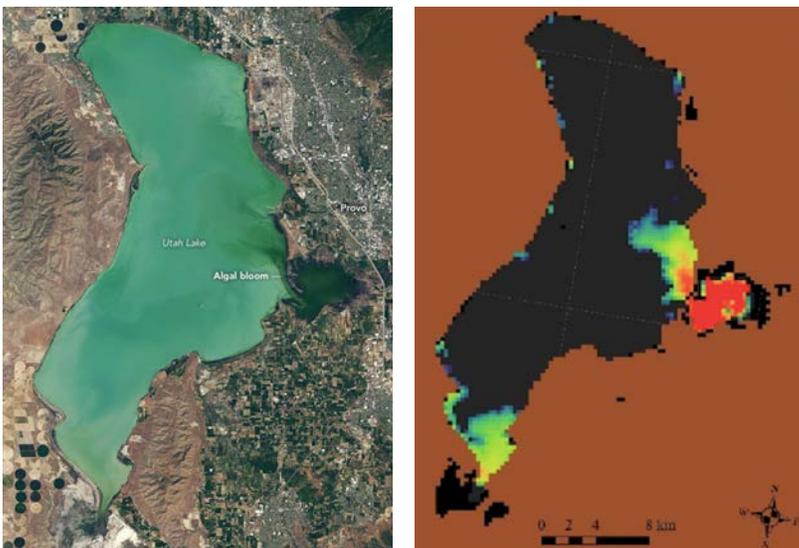


Figure. Images of Utah Lake obtained by Landsat 8 on June 20, 2017, showing the algal bloom as a darker water color [left] and by the European Space Agency's Copernicus Sentinel-3 satellite on June 21, 2017 [right]. Light shades in the Sentinel-3 image show elevated concentrations of cyanobacteria (algae), with black indicating undetectable levels. **Image credit:** NASA's Earth Observatory [left]; Sentinel-3 [right]

Quality to test the bloom for toxicity earlier than observations on the ground alone would have enabled. This information allowed Utah public health and environmental officials to post warnings to boaters, swimmers, and fishers on June 29. The Figure on page 34 shows two examples of satellite data obtained over Utah Lake.

The researchers then ran a second scenario for this Utah Lake bloom, but without including the satellite-enabled detection and concluded that public health warnings would not have been posted until July 6. They estimated the seven-day delay would be due to the time it takes on average for a bloom to be reported, on-site testing to occur, analysis of testing results, the decision to post

warnings, and finally the time it takes to post a warning. The delay would have allowed humans and other animals in the water with the harmful algae. The authors then referenced health economics literature and estimated the costs of that exposure to the local community.

Robertson said the case study was part of a larger effort to develop a framework to measure the economic benefits of detecting harmful algal blooms.

“Incorporating satellite data into the harmful algal blooms detection strategy for other large U.S. lakes could yield similar benefits,” said Robertson. ■

NASA Snow Campaign Wraps 2020 Survey

continued from page 33

As snow melts and gets wetter in the spring, it becomes more challenging to measure. From December 2019 through March 2020, smaller local teams took weekly ground measurements and bimonthly air surveys at 13 sites that span different snow climates, in five different states around the western U.S.

Even though the campaign wrapped up early due to the coronavirus pandemic, the team’s wide variety of sampling sites gave them enough data to validate and analyze, said Vuyovich and Marshall. During each overflight, teams at each site measured and entered data into the National Snow and Ice Data Center’s system designed for SnowEx, and both scientists conducted regular check-in calls via videoconferencing.

“There were definitely challenges in remotely managing such a large campaign, but it was a great learning experience,” Vuyovich said. “This kind of campaign is valuable, so knowing what worked and didn’t work has helped us talk about future years and how we might structure things differently.”

The team’s next step is to process and freely distribute the millions of data points they collected at Grand Mesa and during the time series. Marshall indicated that they expect to begin finding results later in the year. “This large dataset will be used to help design a future spaceborne approach to mapping SWE globally, using a combination of ground observations, models,



Photo 3. Carrying instruments similar to those used on the ground, this DHC-6 Twin Otter and other aircraft flew over the snow pits, taking similar measurements at the same time for calibration and comparison with ground data. **Photo and text credit:** NASA/Jessica Merzdorf

and satellite measurements. The SnowEx 2020 data will provide information to allow us to explore tradeoffs in cost, complexity, and accuracy.”

To experience the SnowEx 2020 team’s trip to Grand Mesa, check out the bonus episode of NASA’s Curious Universe podcast at <https://go.nasa.gov/3hCnHL4>. It is also described in a shorter video segment found at <https://svs.gsfc.nasa.gov/13610>. ■



NASA Earth Science in the News

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EDITOR'S NOTE: This column is intended to provide a sampling of NASA Earth Science topics reported by online news sources during the past few months. Please note that editorial statements, opinions, or conclusions do not necessarily reflect the positions of NASA. There may be some slight editing in places primarily to match the style used in *The Earth Observer*.

NASA Says Conditions Right for Fire to Tear Through Amazon and Hurricanes to Form, July 10, 2020, *newsweek.com*. This year, the North Atlantic has been experiencing warmer than average sea surface temperatures. According to scientists, these conditions are setting the stage for a particularly active fire season in the southern Amazon rainforest, while also raising the risk of hurricanes forming. Based on climate conditions this year, the latest Amazon fire forecast, co-created by **Doug Morton** [NASA's Goddard Space Flight Center] and **Yang Chen** [University of California, Irvine], suggests the fire season may be as severe as 2005 and 2010, which saw record droughts in the rainforest and significant fire activity, accompanied by an active Atlantic hurricane season. "The fire season forecast is consistent with what we saw in 2005 and 2010, when warm Atlantic sea surface temperatures spawned a series of severe hurricanes and triggered record droughts across the southern Amazon that culminated in widespread Amazon forest fires," Morton said in a statement. "Our seasonal fire forecast provides an early indication of fire risk to guide preparations across the region," Morton said. "Now, satellite-based estimates of active fires and rainfall will be the best guide to how the 2020 fire season unfolds." Morton and Chen say the severity of the fires this year may even be exacerbated by the ongoing COVID-19 pandemic, which could hamper the work of emergency responders. "You have a perfect storm: drought, the recent increase in deforestation, and new difficulties for firefighting. 2020 is set up to be a dangerous year for fires in the Amazon," Morton said.

***NASA Teams with Japan, Europe for COVID-19 Global Impacts Project**, June 25, 2020, *space.com*. Three space agencies have pulled together data monitoring the global impact of the COVID-19 pandemic into one joint information source in hopes of assisting understanding of the public health crisis. NASA, the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA) unveiled their joint coronavirus dashboard during a news conference

on June 25, 2020. The dashboard tracks not the respiratory disease itself, but consequences of the public health measures implemented in hopes of slowing its spread, like closing borders and mandating social distancing tactics. "On Earth we are connected," **Thomas Zurbuchen** [NASA Headquarters—Associate Administrator for Science] said during the news conference. "[The dashboard] demonstrates the key capability that is important for all these global types of issues."

NASA Shares Mind-Blowing Photo of 'Upside-Down City' Beneath the Clouds, June 24, 2020, *mirror.uk.co*. At first glance, a photo featured as NASA's Astronomy Picture of the Day (<https://apod.nasa.gov/apod/ap200624.html>)—see **Photo** on page 37—you'd be forgiven for mistaking it as a still from the latest science fiction blockbuster. But the photo is very much real and shows what appears to be an upside-down city beneath the clouds. The incredible photo was snapped by photographer **Mark Hersch**. NASA explained, "How could that city be upside-down? The city, Chicago, was actually perfectly right-side up. The long shadows it projected onto nearby Lake Michigan near sunset, however, when seen in reflection, made the buildings appear inverted." Hersch snapped the photo while on an airplane on approach to Chicago's O'Hare International Airport. "The Sun can be seen both above and below the cloud deck, with the latter reflected in the calm lake," explains NASA.

NASA Images Show Extreme Heat and Fires Raging Across Siberia, June 24, 2020, *newsweek.com*. NASA's Earth Observatory has released a map and image providing insights into the extraordinary heat that has affected Siberia this year, and the wildfires that are raging across the region—see **Figure 1** on page 37 and **Figure 2** on page 38. Siberian towns at high latitudes have been experiencing abnormally high temperatures. A scorching heat wave in the east of the vast Russian region has already produced what may be the hottest temperature ever recorded in the entire Arctic circle. On Saturday, June 20, 2020, the



Photo. This incredible photo was snapped by photographer Mark Hersch and has been featured as NASA's Astronomy Picture of the Day. **Photo credit:** Mark Hersch/NASA

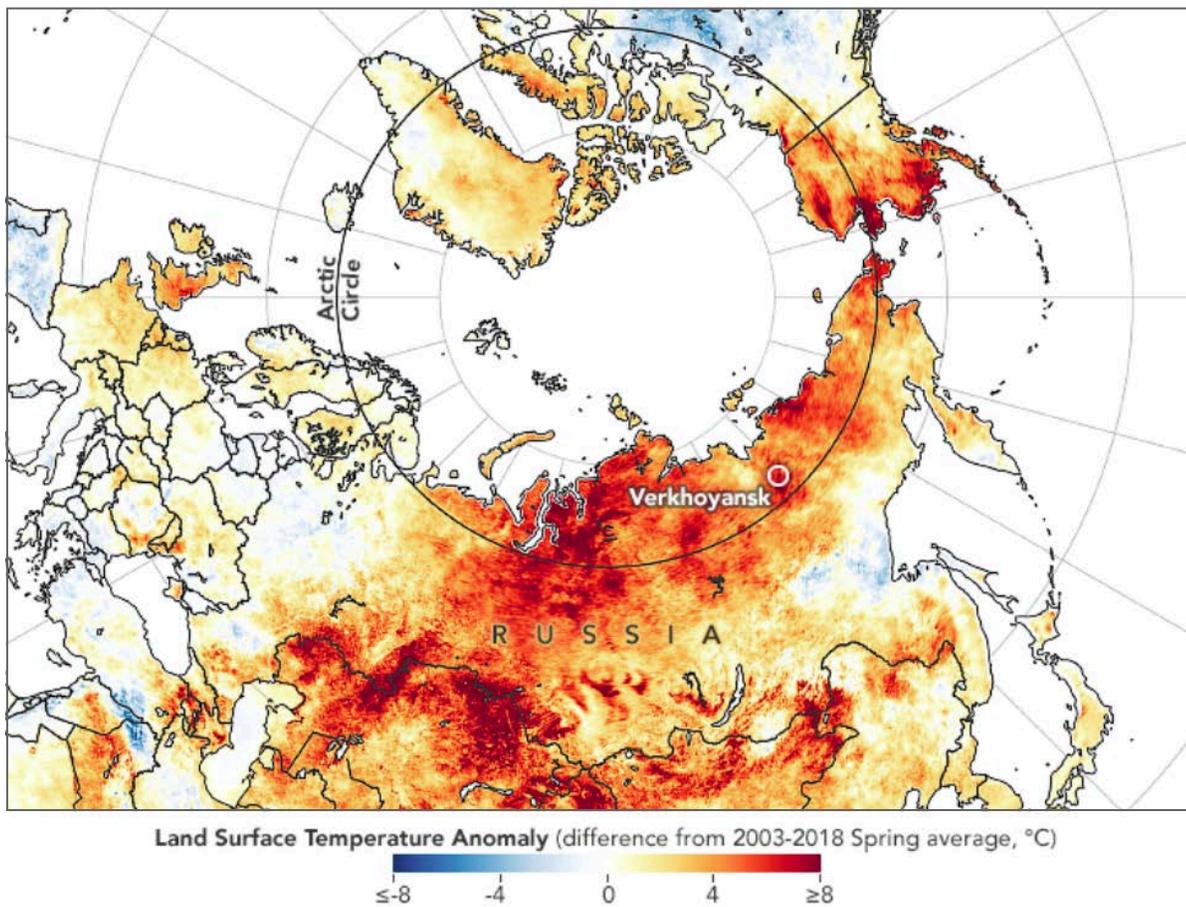


Figure 1. This map shows land surface temperature anomalies from March 19 to June 20, 2020. Dark red depicts areas that were hotter than average for the same period from 2003-2018; Blue areas were colder than average. The map is based on data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite. Note that the map depicts land surface temperatures (LSTs), not air temperatures. LSTs reflect how hot the surface of the Earth would feel to the touch and can sometimes be significantly hotter or cooler than air temperatures. **Image credit:** NASA's Earth Observatory

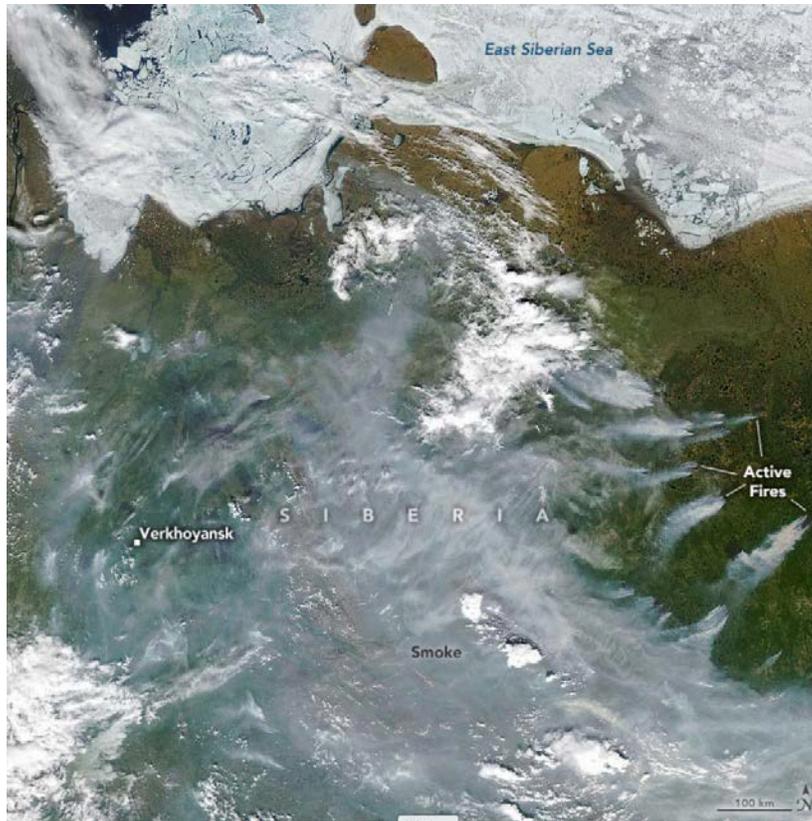


Figure 2. This image, created using data from the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (NPP) satellite, shows active fires burning in Siberia on June 23, 2020. **Image credit:** NASA's Earth Observatory

mercury in the small town of Verkhoyansk, 3000 mi (4828 km) east of Moscow, reached 100.4 °F (38 °C), according to Russian weather data, which has yet to be verified. “This event seems very anomalous in the last hundred years or so,” **Gavin Schmidt** [NASA’s Goddard Institute for Space Studies—*Director*] said in a statement. Verkhoyansk experiences some of the coldest temperatures on Earth during the winter. In fact, the mercury plunged to nearly -60 °F (-51 °C) in November 2019. But while large portions of Siberia are no stranger to hot summers, Verkhoyansk itself, which is located around six miles north of the Arctic circle, rarely sees temperatures above -70 °F (21 °C). Experts say the extreme heat seen in Verkhoyansk can be explained by a vast high pressure system that is sending the mercury soaring across eastern Siberia, where

the town is located. However, human-driven climate change is causing the Arctic to warm more than two times faster than the average for the rest of the planet.

* See news story in this issue.

*Interested in getting your research out to the general public, educators, and the scientific community? Please contact **Ellen Gray** on NASA’s Earth Science News Team at ellen.t.gray@nasa.gov and let her know of upcoming journal articles, new satellite images, or conference presentations that you think would be of interest to the readership of **The Earth Observer**. ■*

Earth Science Meeting and Workshop Calendar

NASA Community

September 11&14, 2020

SnowEx Virtual Meeting, *virtual*
<https://snow.nasa.gov/upcoming-events>

September 15–18, 2020

CERES Science Team Meeting, *virtual*
<https://ceres.larc.nasa.gov/ces-science-team-meetings>

September 23–24, 2020

PACE Applications Workshop, *virtual*
<https://pace.oceansciences.org/events.htm>

October 6–8, 2020

DSCOVER Science Team Meeting, *virtual*
<http://epic.gsfc.nasa.gov>

October 19–21, 2020

LCLUC Annual Science Team Meeting, *virtual*
<https://lcluc.umd.edu>

October 19–23, 2020

PMM Science Team Meeting, *virtual*
<https://gpm.nasa.gov>

October 27–29, 2020

GRACE–FO Science Team Meeting
Potsdam, Germany
<https://grace.jpl.nasa.gov/events>

November 2–5, 2020

GPM-ACCP Transport and Logistics
Workshop, *virtual*
<https://gpm.nasa.gov/science/meetings>

Global Science Community

September 26–October 2, 2020

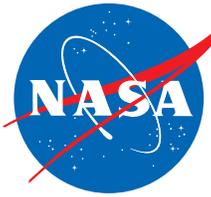
IEEE International Geoscience and Remote Sensing
Symposium (IGARSS) 2020, *virtual*
<https://igarss2020.org>

October 26–30, 2020

Geological Society of America (GSA), *virtual*
<https://community.geosociety.org/gsa2020/home>

December 1–17, 2020

AGU Fall Meeting, *virtual*
<https://www.agu.org/fall-meeting>



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Article submissions, contributions to the meeting calendar, and other suggestions for content are welcomed. Contributions to the calendars should contain date, location (if meeting in person), URL, and point of contact if applicable. Newsletter content is due on the weekday closest to the first of the month preceding the publication—e.g., December 1 for the January–February issue; February 1 for March–April, and so on.

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